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FORMERLY UTILIZED MED/AEC SITES REMEDIAL ACTION PROGRAM

RADIOLOGICAL SURVEY
OF
THE ALBANY METALLURGICAL RESEARCH CENTER
UNITED STATES BUREAU OF MINES
BIOMASS FACILITY AND THE
"BACK FORTY" AREA
ALBANY, OREGON

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PREFACE AND EXECUTIVE SUMMARY

This is one in a series of reports resulting from a program initiated in 1974 by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineer District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940s, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

This report contains survey results identifying the current radiological condition of two areas located at the site of the United States Bureau of Mines' Albany Metallurgical Research Center in Albany, Oregon. These areas are designated as the "BioMass Facility" and the "Back Forty." The BioMass Facility was a pilot plant for the production of oil from wood waste; it consists of five structures on a two-acre site. The Back Forty is a vacant area of about 14 acres south of the BioMass Facility. Both areas were reportedly used as dump sites for the Bureau of Mines operations.

During the periods 1954 to 1956 and 1960 to 1971, the Albany Metallurigcal Research Center was engaged in metallurgical operations that included melting, machining, welding, and alloying of thorium. Research on alloys of uranium and thorium started in 1955 and continued until suspended in 1978.

Records indicated that at the time the AEC contract was terminated, the buildings and surrounding areas were decontaminated to the general guidelines provided by the AEC. Those guidelines were not as specific as current guidelines, and details of the final decontamination are not documented.

To determine if any radioactive contamination remains as a result of MED/AEC activities, a radiological assessment of the entire Albany Bureau of Mines site was initiated in June 1978. During September 1979, a survey was performed in the 14-acre field referred to as the "Back Forty." A preliminary survey of the BioMass Facility was undertaken at the same time. During September 1980, subsurface investigations of both the BioMass Facility and the Back Forty area were conducted. During September 1982, a detailed radiological survey of all structures, equipment, and material at the BioMass Facility was completed.

The BioMass Facility survey included use of gas-flow proportional detectors for alpha and/or beta-gamma radiation and NaI crystal detectors for ambient penetrating (gamma/x-ray) radiation; air sampling to determine radon, thoron, and actinon concentrations and Working Level determinations within each structure; use of pressurized ion chambers to measure ambient radiation, both differential and integral with respect to time, at the 3 ft level; and surveying of all exterior ground surfaces with gas-flow proportional detectors for alpha and/or beta-gamma radiation and NaI crystal detectors for gamma and x-ray radiation; and analysis of subsurface samples from exterior areas.

The radiological survey of the Back Forty area consisted of surface and subsurface investigations. A ground-surface survey of the vacant land was conducted with gas-flow proportional detectors for alpha and/or beta-gamma radiation and NaI crystal detectors for gamma/x-ray radiation. Several measurements of the ambient radiation at the 3-ft level were also made using a pressurized ion chamber.

The subsurface investigations for both sites consisted of obtaining and analyzing "environmental" soil samples (4 in. diameter by 12 in. deep) and bore-hole samples (drilled to 10-ft depths). The environmental samples were partitioned into sequential segments of 2-in., 2-in., 2-in., and 6-in. thicknesses. The bore holes were sampled in continuous 1-ft increments (split-spoon), and prior to backfilling, each hole was logged with a 2-in. x 2-in. NaI(Tℓ) detector. All soil samples were analyzed for uranium by use of fluorometry, and for radium and thorium by use of high-resolution gamma spectrometric techniques. Radiochemical separation procedures and alpha spectroscopic techniques were used to further analyze some samples for thorium isotopes.

Two environmental samples were obtained and 8 bore holes were drilled in the BioMass area; 7 environmental samples were obtained and 18 bore holes were drilled in the Back Forty area.

No contamination was found to be associated with the structures, equipment, or material in the BioMass Facility; however, four relatively small areas of contamination were found in the exterior grounds. The maximum radiation level measured was 0.7 mR/h at 1 cm.

A relatively large area (~ 0.8 acre) in the Back Forty area exhibited anomalous radiation levels. Radiation levels as high as 100 μR/h were measured at 3 ft above ground. This area was reportedly used as a dump site for Bureau of Mines activities.

The structures, equipment, and material associated with the BioMass Facility can be released for unrestricted use. However, because of the subsurface contamination found in both the BioMass and the Back Forty areas, some restrictions should be incorporated into any planned useage for this site. Some discussion regarding these hazards are included in the text of this report.

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THE ALBANY METALLURGICAL RESEARCH CENTER
UNITED STATES BUREAU OF MINES
BIOMASS FACILITY AND "BACK FORTY" AREA
ALBANY, OREGON

INTRODUCTION

During the Manhattan Engineer District/Atomic Energy Commission (MED/AEC) era, some work involving radioactive materials was performed at the Albany Metallurgical Research Center of the United States Bureau of Mines in Albany, Oregon (see Fig. 1). During the periods 1954 to 1956 and 1960 to 1971, metallurgical operations involving melting, machining, welding, and alloying thorium were conducted at the site. Also, these operations included research on alloys of both uranium and thorium started in 1955 with some activities continuing until 1978 under Contract No. E(04-3)-906.

When the contract was suspended in 1978, records indicated that structures of concern were decontaminated in accordance with general guidelines prescribed at the time. Those guidelines, however, were not as specific as current guidelines. Likewise, details of certain of the final decontamination activities were not documented to the extent necessary, particularly for the case of those activities which occurred in the 1950s. As a consequence, U.S. Department of Energy (DOE) has undertaken a radiological characterization and assessment study to determine the radiological condition of this site. This study was initiated as part of a DOE program intended to ensure that residual radioactive material from past MED/AEC operations do not pose undue present or future radiological hazards. Although the entire Albany Metallurgical Research Center site has undergone a comprehensive radiological survey, this report deals exclusively with the survey activities associated with the BioMass Facility and the Back Forty portions of the site. Survey results for the remainder of the site are presented in a companion report (ANL-OHS/HP-83-102).

The BioMass Facility, also called the Wood Waste to Oil Pilot Plant and/or the Albany BioMass Liquification Facility, is located on the southeastern corner of the fenced portion of the Bureau of Mines site (see Fig. 2). It covers area about two acres and contains five structures--No. 35 (Control Buildin No. 36 (Maintenance Shop), No. 37 (Process Building), No. 38 (Compres Building), and No. 39 (Office Building) (Fig. 3). The Process Building i multistage structure similar to a fractional distillation tower; all ot structures are of standard metal (Butler type) or masonry (concrete blo construction. Construction of the BioMass Facility was completed in 19 Operators of the facility have included the Bechtel Corporation from 1976 1978, and Rust Engineering, a division of the Wheelabrator-Frye Corporatio from 1978 to 1981, when operations were terminated.

As far as can be determined from discussions with Bureau of Mines person and former operators of the BioMass Facility, no radioactive material, exce for a sealed source (either ^{137}Cs-^{137m}Ba or ^{60}Co) used as a level gauge, w knowingly involved in the Facility or in the process operations. A representative of the last firm to operate the facility confirmed that the sealed sourc had been returned to the manufacturer prior to initiation of the radiologica assessment activities reported in this document.

The Back Forty is a 14-acre area located in the southern portion of th Bureau of Mines site. It is bounded on the north by the fenced portion of th site, on the east by Liberty Street, on the west by Broadway Street, and on th south by the Tennis Club (see Fig. 2). The area consists of vacant land crosse by two high-voltage transmission lines. Only one line is indicated on maps of the area. One line, belonging to the Bonneville Power Administration (BPA) runs from the southern boundary of the property in a northwestern direction and exits at Broadway approximately in the center of the Back Forty. This line is a single-circuit 115 kV transmission line. The second line, not evident on city or county maps, runs from east to west at the approximate center of the property. This line is a single-circuit, 115 kV, transmission line with a local power line approximately halfway down the poles. The line is owned by the Pacific Power and Light (PPL).

Both the Back Forty and the area subsequently used for the BioMass Facility, were reportedly used as dump sites for the Bureau of Mines operations. Material disposed of included natural uranium and its associated decay products, natural thorium and its associated decay products, normal uranium, and possibly radionuclides of the mesothorium chain (^{228}Ra, ^{228}Ac, ^{228}Th).

SURVEY AND ANALYTICAL TECHNIQUES

General

This radiological survey, which was performed by the Argonne National Laboratory Radiological Survey Group for the U.S. Department of Energy, encompassed all structures in the BioMass Facility; all lawns, paved areas, and docks in the BioMass Facility area; and the entire open field area known as the Back Forty south of the BioMass Facility. In addition, subsurface investigations of suspected contaminated areas were conducted.

Within the buildings, all accessible floors, walls (to a height of 7 ft), equipment, and material were surveyed. A representative selection of overhead structures, such as pipes, vents, and light fixtures, were surveyed where present. Smear surveys for removable contamination were taken from the floors, walls, and overheads of all buildings. The surfaces of all exterior ground areas were surveyed in their entirety.

Instrumentation

Four types of portable survey instruments were used to conduct the direct radiological surveys. Gas-flow proportional detectors with window areas of 51 cm^2 and 325 cm^2 (using Eberline PAC-4G-3 electronics) were used to monitor for alpha and/or beta-gamma radiation. NaI crystal detectors, 2 in. diameter by 2 mm thick (Eberline PG-2 with Eberline PRM-5-3 electronics), were used to monitor for low energy x-ray and gamma radiation. NaI crystal detectors, measuring 1 in. diameter by 1 in. thick (Eberline PRM-7 μR meter) and calibrated with a ^{226}Ra standard source, were used to measure the ambient external penetrating radiation field (μR/h). An end-window Geiger-Mueller (GM) detector (Eberline HP-190 with a 7 mg/cm^2 window and Eberline 530 electronics), calibrated with a ^{226}Ra standard source, was used to measure the contact exposure rate (mR/h) of contaminated areas. Integrated measurements of the ambient penetrating radiation field were taken with a pressurized ionization chamber (Reuter Stokes RSS-111) calibrated with an NBS traceable ^{137}Cs-^{137m}Ba gamma-ray source. These instruments and associated calibration procedures are detailed in Appendices 1 and 2.

When possible, a contaminant was identified by performing gamma spect analysis on either the contaminated item or on a sample of material taken fro contaminated area. These analyses were performed with a sodium iodide and/ hyperpure germanium detector coupled to a multichannel analyzer. This instr mentation is also described in Appendix 1.

Smear Surveys

Dry smears were taken at representative locations throughout each buildi with 4.25-cm-diameter filter papers (Whatman #1). A standard smear sample i obtained by applying moderate pressure with the tips of the first two fingers t the back of the filter paper and wiping the surface over an area of about 900 c Smears were taken on original structures and components such as walls, floors pipes, and vents. A smear of 100 cm^2 was taken fron any area or object indicat by a portable survey instrument to have a higher than normal radiation level. smear of a 100-cm^2 area was also taken if the surface was extremely dusty.

To expedite counting of the numerous smear samples collected, two counting techniques were employed with two types of counters. A large-area, thin-window, gas-flow proportional counter sensitive to alpha and/or beta-gamma radiation was used to make an initial count on groups of smears. For confirmatory counts on individual smears noted to be above the expected background level and for other special counting, a Nuclear Measurement Corporation Model PC-5 (or 3A), internal gas-flow proportional counter (PC counter) with a thin aluminized Mylar window (referred to as Mylar spun top) was used.

Initial counts were made with the large-area counter on groups of ten smears at a time. Smears from any group indicating a reading above the instrument background were then counted individually in the PC counter. In addition, at least one smear of each group of ten was selected at random and counted in the PC counter. All smears of the areas or objects with elevated direct readings were counted individually in the PC counter. A more detailed description of the counters and of the counting and calibration techniques is presented in Appendix 1.

Air Samples

Air-particulate samples were collected using a commercial vacuum cleaner (ANL-modified) to pull air through filter media (Hollingsworth-Vose HV-70). A total volume of 26.7 m^3 of air was sampled at a flow rate of 40 m^3/h. A 10% portion (5 cm in diameter) was removed from the filter media after collection and counted for both alpha and beta-gamma activity in the PC counter. Radon (^{222}Rn), thoron (^{220}Rn), and the presence of any long-lived airborne radionuclides were determined based on the result of several counts of each sample at specified intervals.

Air-particulate samples were also collected on Millipore Filter media for 40 minutes at a flow rate of approximately 1.5 m^3/h. A portion of each filter sample was used for alpha spectral analysis to determine the actinon (^{219}Rn) concentration.

Details of air-sampling techniques and associated calculations are given in Appendix 3.

Soil Corings

Environmental soil samples (4-in. diameter, 12-in.-deep corings) were taken from two selected undisturbed locations on unpaved grounds of the BioMass Facility and from seven separate locations throughout the Back Forty. Duplicate corings were taken at two additional sites, private residences in Albany [Fig. 1], to determine background levels of radiological contaminants for the area. Uranium and gamma spectral analyses were conducted on all samples.

The samples were collected using a 4-in.-diameter, 6-in.-long right-circular-cylinder cutting tool, commonly used as a golf-green hole-cutter. Each soil core was 12 in. long and was divided into four segments for analysis. Starting from the surface, three, 2 in. segments were cut, bagged, and marked A, B, and C, respectively; the final segment of 6 in. was marked D.

The segmented coring technique was used to determine if any contaminant migration had occurred; to reduce the dilution of lower-level soil with the upper-level segments with respect to the surface deposition of the contaminants, or vice versa; and to reveal if any overburden or backfill had been added.

Soil Borings

Bore holes were drilled in areas exhibiting elevated radiation levels on the BioMass Facility grounds and the Back Forty. Samples were taken from the hole in sequential 1-ft. sections using a split-spoon sampler (1½-in. inside diameter). The depth of the bore holes ranged to 10 ft. The bore holes were identified by a number (e.g., 7-S56), and each sample was identified according to depth in feet (e.g., 7-S56-2.0 equates to bore hole 7-S56 sample from 1.0 to 2.0 ft below the surface). Depths were reported to the nearest tenth of a foot.

Soil Analyses

Soil samples were prepared at ANL as detailed in Appendix 4 and shipped either to a commercial laboratory (LFE Environmental Analysis Laboratories) or to the Analytical Chemistry Section of the Chemical Engineering Division at Argonne National Laboratory for radiochemical and gamma-spectral analysis.

ANALYSIS OF SURVEY RESULTS

General

The gas-flow proportional counter survey data were converted to surface contamination measurements according to the following general procedures (also see Appendix 2). For gross readings taken in the beta mode, background and any alpha contribution were subtracted to determine the net beta-gamma count rate. The net count rate was then converted to disintegrations per minute (dis/min) and normalized to a surface area of 100 cm^2. After subtraction of background, readings in the alpha mode also were converted to dis/min-100 cm^2. Smear samples were counted for both alpha and beta-gamma activity, and the net count rates were converted to dis/min-100 cm^2 after subtracting the appropriate background.

The low-energy x-ray and gamma count rates were measured with the PRM-5-3. The results are reported in counts per minute (cts/min) and include the instrument background of 500 cts/min. The GM detector and μR meter exposure rate measurements include the instrument backgrounds of 0.03-0.05 mR/h and 5-7 μR/h, respectively. The background levels varied somewhat, due primarily to the construction materials in each room.

An average exposure reading was determined with the μR meter in each building where floor and wall surveys were performed. These readings are referred to as the "Radiation Exposure Level (1 meter)" and are reported in units of μR/h. Additionally, an integrated measurement of the ambient radiation field at select locations was taken with a pressurized ion chamber

All instrument survey results which were greater than the instrument backgrounds are reported in this document. Levels of contamination, as well as the contaminating radionuclides, are identified.

The instrument survey data and the smear results were reviewed with respect to both the ANSI Standard N13.12, "Control of Radioactive Surface Contamination of Facilities To Be Released for Uncontrolled Use", and the NRC's "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material." (See Appendix 6.)

Instrument and Smear Surveys

Surface surveys were performed with an Eberline FM-4G equipped with PAC-4G-3 electronics (a propane gas-flow proportional counter with a window area of 325 cm^2); an Eberline PAC-4G-3 (a propane gas-flow proportional counter with a window area of 51 cm^2); and a PRM-5-3 with PG-2 detector, (a 2-mm thick by 2-in. diameter NaI{Tℓ} detector). In all but one case, the readings indicated background levels. The one exception was the glazed tile in the washrooms. Elevated radiation readings from glazed tile are due to natural radioactive material that migrates to the surface as a result of firing in the kiln.

Swipe smears of the walls and floors, counted in the 10 wire proportional counter and/or the 2π internal gas-flow proportional counter utilizing a Mylar spun top, indicated no smearable contamination.

Integrated background readings taken at selected locations with a pressurized ion chamber (Reuter-Stokes RSS-111 ^{60}Co calibrated) indicated an exposure rate from 8 to 10 μR/h.

A general survey of the area using the Eberline PRM-7, indicated readings of about 7 μR/h (^{137}Cs-^{137m}Ba calibrated). This corresponds to the 8 to 10 μR/h

exposure rate measured by the pressurized ion chamber. The difference in
is due to the slight difference in the energy response of the detectors.

The survey of the BioMass Facility grounds detected four small are
contamination. The maximum external beta-gamma radiation level was 0.7 mR
1 cm, as measured with the thin End Window GM detector through approxim
7 mg/cm^2 of total absorber. A maximum exposure rate of 30 μR/h at the
level was obtained at this location with the RSS-111 pressurized ion cham

The approximate locations of the four areas of contamination (identifie
328, 329, 330, and 331) are shown in Figure 3. A detailed drawing of the Bi
Facility identifying exact locations of the contaminated areas as well as e
locations of all subsurface sampling holes, is presented in Figure 7. The
ordinates for each hole identified in this drawing are given in Table 7.

Contamination was also detected in the Back Forty area, including a re
tively large area that exhibited anomalous radiation levels. This contamina
area is located just south of the BioMass Facility and covers an area
approximately 0.8 acres (see cross-hatched area of Figure 4). Exposure ra
measured with the PRM-7 survey instrument ranged from background to 100 μR/h
3 ft above ground. General outdoor background in the Bureau of Mines area
about 7 μR/h. Several Reuter-Stokes integrated determinations at 3 ft abo
ground level ranged from 10.8 μR/h to 32.8 μR/h in and about the general are
A detailed drawing of the Back Forty area showing locations of contaminat
areas and of all subsurface sampling holes is presented in Figure 8. The c
ordinates for each hole identified in the drawing are given in Table 7.

The ground survey results for both the BioMass Facility and Back Forty are
are summarized in Table 1.

Air Samples

Analysis of air samples taken throughout the BioMass Facility indicate
levels of radon (^{222}Rn) progeny that ranged from 0.0005 to 0.0094 Working Level
(WL). Concentrations of thoron (^{220}Rn) were considerably lower than those of
radon (^{222}Rn), and no actinon (^{219}Rn) was observed above detectable limits.
Details of air sampling procedures and associated calculations are given in
Appendix 3; the results of the analyses are tabulated in Table 2.

Soil Corings

Two soil corings (7-S39 and 7-S40), were taken within the grounds of the BioMass Facility, and seven soil corings (7-S26 through 7-S32), were taken from the Back Forty area. The locations where these corings were taken are shown in Figure 5.

Duplicate corings were taken from two additional sites, private residences in Albany (see Fig. 1), to determine background levels for the Albany area. These soil corings have been identified as 7-SB1 through 7-SB4.

All soil corings were sectioned and analyzed for uranium (uranium fluorometric) and for radionuclides of the radium and thorium decay chains (gamma spectral analysis). Results are included in Table 4.

Soil Borings

A total of eight bore holes were drilled to a depth of 10 ft within the grounds of BioMass Facility. These bore holes have been identified as 7-S65 through 7-S72, and the location of each is shown in Figure 6. Split-spoon samples were taken from these bore holes at continuous 1-ft increments. Bore-hole logging was accomplished using a 2-in. x 2-in. NaI(Tℓ) detector in conjunction with a ND-100 multichannel analyzer, a teletype printer as the hardcopy readout, and punched tape storage. Readings were taken at grade level and at 2-ft increments thereafter. Analysis of the soil samples taken from the bore holes revealed levels of radioactive materials in the soil that ranged from background (approximately 1.6 pCi/g average) to 234 ± 21 pCi/g for the uranium series and from background (approximately 1.0 pCi/g average) to 38.6 ± 0.6 pCi/g for the thorium series. This elevated activity was found primarily at the 3- to 6-ft level in an area adjacent to Building 37 (Process Building) and on a line extending north to Building 35 (Control Building).

Eighteen bore holes were drilled to a depth of 10 ft in the Back Forty area. These bore holes have been identified as 7-S56 through 7-S64 and 7-S73 through 7-S81; locations are shown in Figure 6. Split-spoon soil samples were taken and bore-hole logging was accomplished as previously described.

Results of the subsurface investigation for the Back Forty area indicated the highest level of radioactive contamination to be concentrated in the grade to 2-ft level. However, elevated concentrations were found as deep as 9 ft below grade. Maximum soil concentrations, as determined by gamma-spect analysis (0.609 MeV for the ^{226}Ra chain and 0.908 MeV for the ^{232}Th chain), w 33.2 pCi/g ^{226}Ra and 57.7 pCi/g ^{232}Th. The maximum uranium soil concentrati as determined by the uranium fluorometric method, was 34 pCi/g.

Nine auxilliary subsurface samples were taken from a water line di running east/west along the north end of the BioMass Facility (Fig. 3). Th samples were identified as 7-S89 through 7-S92 and 7-S94 through 7-S98. Sam 7-S92 was taken from a depth of 1 ft; all the other samples were taken from 3 ft depth.

Two water samples were taken in the course of the subsurface investigati One sample was taken from borehole 7-S73 in the "Back Forty" area and has be identified as 7-W88. The second sample was taken from an open pit (oil separa in the BioMass Facility east of Building 35. This latter sample has be identified as 7-W132.

The many analyses conducted have indicated some discrepancies between t gamma spectral results and the uranium fluorometric results. When the ^{226} concentration, as determined by gamma-spectral analysis, appears greater th the uranium concentration, as determined by the uranium fluorometric analysi this is indicative of radium enhancement similar to that found in mill tailing When the reverse of this is found, it is an indication that <u>normal</u> (i.e uranium that has <u>been</u> separated from its daughters) and <u>not</u> <u>natural</u> (i.e uranium in equilibrium with its daughters) uranium is present. Both ratios we found in several of the analyses conducted for this survey, indicating th buried contaminants may be more diverse than just natural uranium and natur thorium with their progeny.

It should be noted that a hydrostatic head was encountered in all bore hol operations throughout the Albany Bureau of Mines survey. Water would generall be encountered at the 8- to 9-ft depth during the drilling operation. After to 2 hours, water would rise to the 4½-ft level, and in one case, to the 1-f level. The source of the hydrostatic head has not been identified by investigations conducted during these operations. It should also be noted that sinc subsurface water is directly involved with the dump contaminants, it is possibl that the contaminants are subject to subsurface lateral migration, thus potentially expanding the area of contamination from that presently depicted.

All soil samples were prepared as outlined in Appendix 4. Soil sampl weights are tabulated in Table 3. Results of the uranium fluorometric analyse and gamma-spectral analyses for all soil samples are given in Table 4. The results of the analyses for the two water samples are given in Table 5.

Four of the soil samples that contained elevated levels of thorium were analyzed by radiochemical separation followed by alpha spectroscopy. This technique allows for the determination of the relative intensity of the various thorium isotopes and hence the degree, if any, of disequilibrium. The results of these analyses are given in Table 6.

ESTIMATED EXTENT OF CONTAMINATION

Estimating the total volume, mass and quantity of radioactive material involved in the BioMass Facility and Back Forty areas is subject to many uncertainties. For example, due to the numerous structures erected over the former dump area that comprises the BioMass Facility, the location of the bore holes were biased to areas of accessability, and the number of bore holes were limited. This creates an uncertainty as to the depth and extent of the buried radioactive material. The total area under the BioMass Facility is assumed to be contaminated, and the average and maximum depths of the contaminants have been determined on the basis of the data from the bore holes and core holes taken in this area.

The Back Forty section of this dump area is reasonably well defined with the exception of possible lateral migration via subsurface fracture. Subsurface profile analysis, based on the soil analyses, reveals the contaminants in both areas to be widely diverse in their concentration, depth, and type of radionuclides encountered. This is to be expected since the waste was disposed of in a sporadic manner, from a number of different operations, and contained both radioactive and nonradioactive material.

Radiological assessment of the structures and equipment of the BioMass Facility revealed no contamination; therefore, the soil (substrata) under the BioMass Facility and the contaminated soil of the Back Forty will be the only material considered for estimating the volume, mass of soil, and the quantities of radioactive material involved.

For this evaluation, the following assumptions are made:

1. The entire area under the BioMass Facility, consisting of approximately two acres, and the contaminated area of the Back Forty, comprising approximately 0.8 acre, contains radioactive material in varying concentrations.

2. The depth of the contaminants will be averaged (Option #1) and maximized (Option #2) in each area. Contaminant depth in the BioMass averaged 4-ft and the maximum depth was found to be 6-ft. Contaminant depth in the Back Forty averaged 3.6 feet and the maximum depth was 9 ft.

3. The average concentration of each radionuclide chain was as follows:

Radionuclides	BioMass Facility (pCi/g)	Back Forty (pCi/g)
^{226}Ra Chain	85	14
Natural Thorium	342	33
Natural Uranium	68	21
Normal Uranium	26	18

The maximum measured concentration of each radionuclide chain was as follows:

Radionuclides	BioMass Facility (pCi/g)	Location	Back Forty (pCi/g)	Location
^{226}Ra Chain	158	7-S39-D	16	7-S73-2
Natural Thorium	3700	7-S39-D	202	7-S28-C
Natural Uranium	196	7-S92-1	87	7-S30-A
Normal Uranium	234	7-S67-3	54	7-S29-C

4. To estimate the total number of curies of each radionuclide in the contaminated areas, the fraction (percent) of the contaminated area where each radionuclide was found has been estimated. This fraction was based on the number of samples where the radionuclide was found compared with the total number of samples exhibiting elevated results. These estimated fractions are as follows:

Radionuclide	BioMass Facility (%)	Back Forty (%)
^{226}Ra Chain	10	5
Natural Thorium	50	60
Natural Uranium	50	60
Normal Uranium	40	30

The volume, mass, and activity of the material involved as estimated on the basis of the above assumptions, are listed in Table 8. Details of these calculations are given in Appendix 7.

DOSE AND POTENTIAL HAZARD EVALUATION

External Exposure

To assess the radiological hazard from external exposure to the radiation source, a "conservative situation" was assumed. Since these areas are no longer occupied, a maximum exposure of 40 hours/week was adopted for this analysis.

The maximum radiation level observed in the Back Forty area was 100 μR/h, including a 7 μR/h background. Hence, the annual dose from this source would be:

$$(100\ \mu R/h - 7\ \mu R/h) \times 40\ h/w \times 52\ w/y \times 1\ rem/R = 0.193\ rem/y$$

The maximum radiation level observed in the BioMass Facility was 50 μR/h including a 7 μR/h background. Hence the annual dose from this source would be:

$$(50\ \mu R/h - 7\ \mu R/h) \times 40\ h/w \times 52\ w/y \times 1\ rem/R = 0.089\ rem/y.$$

Both of these values are well below the DOE 5480.1 limit of 500 millirem per year for a person non-occupationally exposed.(1) Hence, these contaminated areas do not constitute a radiological hazard in terms of external exposure (see Appendix 8).

Internal Exposure

To assess the potential for radiological hazard based on potential intern exposure, it was necessary to assume some "conservative" but neverthele plausible scenarios whereby the radioactive contamination was assimilated i ternally. To this end, two cases were considered. The first case was based (the situation whereby a child would eat 100 g per year of the contaminated soil The second case assumed a home gardener would rototill the contaminated soi (dry) to a 1-ft depth for a working day (eight hours) once a year. For thi latter case, a resuspension factor of 10^{-6} m^{-1} and a breathing rate of 9.6 m^3 working day^2 were used. In both cases it was assumed that the average concentration of contaminants in the soil was equal to the maximum measured value (conservative assumption). All calculations are based on methods outlined i ORNL/NUREG/TM-190, Vol. 3(3). These calculations approximate the ICRP-30 guidelines for hazard analysis.

The maximum concentrations of soil contaminants found in the Back Fort area were 87 pCi/g natural uranium, 200 pCi/g thorium (^{232}Th decay chain), an 42 pCi/g radium (^{226}Ra decay chain). Based on these levels of contamination the following hazard levels (50 year dose commitment for one year of intake) were calculated:

1) Child eating 100 g per year;
(units: mrem/pCi x pCi/g x g = mrem)

Natural uranium:	Bone	(0.033)(87)(100)	=	287 mrem
	Total body	(0.003)(87)(100)	=	26 mrem
Radium (^{226}Ra)	Bone	(0.065)(42)(100)	=	275 mrem
	Total body	(0.006)(42)(100)	=	25 mrem
Natural thorium	Bone	(0.012)(200)(100)	=	240 mrem
	Total body	(0.0019)(200)(100)	=	20 mrem

2) Adult inhalation of aerosol (per year intake):
(units: mrem/pCi x pCi/m^3 x m^3 = mrem)

Natural uranium	Bone	(0.232)(40)(9.6)	=	89 mrem
	Total body	(0.044)(40)(9.6)	=	17 mrem
	Lung	(0.853)(40)(9.6)	=	328 mrem

Radium (^{226}Ra)*	Bone	(0.092)(19)(9.6)	= 17 mrem
	Total body	(0.01)(19)(9.6)	= 2 mrem
	Lung	(0.107)(19)(9.6)	= 20 mrem
Natural thorium	Bone	(0.200)(91)(9.6)	= 175 mrem
	Total body	(0.030)(91)(9.6)	= 26 mrem
	Lung	(0.593)(91)(9.6)	= 518 mrem

Several of these values are in excess of the DOE 5480.1 limits of 170 mrem per year for nonoccupational exposure.(1) This radiological hazard is not insignificant and should be considered when any subsurface work is undertaken or if children are allowed to play in the area (see Appendix 8).

The maximum concentration of soil contaminants found in the BioMass Facility area were 196 pCi/g natural uranium, 3700 pCi/g natural thorium (^{232}Th decay chain) and 166 pCi/g radium (^{226}Ra decay chain). Based on these levels of contamination, the following "50-year dose commitments for one year of intake" were calculated:

1) Child eating 100 g per year
(units: mrem/pCi x pCi/g x g = mrem)

Natural uranium:	Bone	(0.033)(196)(100)	= 647 mrem
	Total Body	(0.003)(196)(100)	= 59 mrem
Radium (^{226}Ra)**	Bone	(0.065)(166)(100)	= 1.08 Rem
	Total body	(0.006)(166)(100)	= 100 mrem
Natural thorium	Bone	(0.012)(3700)(100)	= 4.44 Rem
	Total body	(0.001)(3700)(100)	= 370 mrem

2) Adult inhalation of aerosol (per year intake):
(units: mrem/pCi x pCi/m^3 x m^3 = mrem)

*The radium concentration is about what is expected for the equilibrium concentration from the measured uranium in the soil. Hence this hazard is accounted for in the natural uranium case and should not be included for total dose estimates.

**The radium concentration is in excess of what is expected for equilibrium with the measured uranium concentration.

Natural uranium	Bone	(0.232)(90)(9.6)	= 200 mrem
	Total body	(0.044)(90)(9.6)	= 38 mrem
	Lung	(0.853)(90)(9.6)	= 737 mrem
Radium (^{226}Ra)**	Bone	(0.092)(76)(9.6)	= 67 mrem
	Total body	(0.01)(76)(9.6)	= 7 mrem
	Lung	(0.107)(76)(9.6)	= 78 mrem
Natural thorium	Bone	(0.200)(1692)(9.6)	= 3.25 Rem
	Total body	(0.030)(1692)(9.6)	= 487 mrem
	Lung	(0.593)(1692)(9.6)	= 9.63 Rem

The calculated inhalation values are definitely in excess of the DOE 54 limits of 170 mrem per year for nonoccupational exposure. Hence, this ra logical hazard must be considered when any subsurface work is undertaken o children are allowed to play in the area.

CONCLUSIONS AND RECOMMENDATIONS

BioMass Facility

The complete radiological survey of all the buildings within the BioM Facility revealed no contamination. The ambient radiation level as determi with an integrating fixed position monitor (RSS-111) at 3 ft above the floor 8 to 9 μR/h. This is within the range of background readings for this ar Air samples taken inside the buildings indicated levels of radon (^{222}Rn) prog that ranged from 0.0005 to 0.0094 Working Levels (WL). These values are we below the limit of 0.02 WL for average annual concentration as specified in t EPA Standard (40 CFR 192). Hence, these buildings require no remedial acti and are suitable for unrestricted use.

The radiological survey of the exterior grounds of the BioMass Facili revealed four small areas with elevated radiation levels. These radiati levels ranged up to 25 k cts/min for surface alpha, beta-gamma, up to 35 cts/min for low-energy x-ray and gamma; and up to 50 μR/h for the ambie radiation level at 3 ft. These radiation levels, while not high, are significantly above background. However, since the radiation stems from subsurfac contamination, and the frequency of habitation in the area is relatively low there is no immediate hazard associated with the occupancy of this area.

Subsurface investigation of the contaminated areas revealed contamination consistent with the use of the area as a waste dump. The soil corings (i.e. 1-ft deep samples 7-S39 and 7-S40) revealed elevated levels of the ^{232}Th decay chain up to 1850 pCi/g at the 1-ft level, ^{226}Ra decay chain up to 166 pCi/g at the 1-ft level, and uranium up to 15 pCi/g at the 1-ft level. The auxiliary sample (7-S92) taken at the 1-ft level from the "waterline" ditch also revealed elevated levels for uranium of 196 pCi/g and for the ^{226}Ra decay chain (i.e., ^{226}Ra as determined from the gamma rays from short-lived daughters) of 86 pCi/g.

Analysis of the soil borings (sequential 1-ft samples to a depth of 10 ft designated 7-S65 through 7-S72) revealed the following information regarding the contamination (elevated levels include background):

7-S65	Background levels.
7-S66	Elevated uranium (8 pCi/g) at the first foot only.
7-S67	Elevated ^{232}Th decay chain (38 pCi/g) at the 3-ft level. Slightly elevated ^{226}Ra decay chain (2 pCi/g) at the 3-ft level. Greatly enhanced uranium (234 pCi/g) at the 3-ft level.
7-S69	Elevated uranium (8 pCi/g) at the 3-ft level.
7-S70	Slightly elevated ^{232}Th decay chain (2 pCi/g) at the first foot. Slightly elevated uranium (3.5 pCi/g) at the first foot.
7-S71	Background levels.
7-S72	Slightly elevated ^{232}Th decay chain (3 pCi/g) at the first foot. Slightly elevated ^{226}Ra chain (3 pCi/g) at the first foot. Elevated uranium (7 pCi/g) at the first foot.

These results indicate that the contamination is subsurface, occurring in the first 4-ft, with the more elevated contamination levels being 3700 pCi/g of natural thorium (sample 7-S39 at 1 ft) and 234 pCi/g of normal uranium (sample 7-S67 at 3 ft). The contamination seems to consist of normal uranium, natural uranium, uranium daughters (e.g. tailings), and natural thorium. The relative amount of each component seems to vary throughout the contaminated areas. The radon daughter concentration in the outside areas was, as expected, relatively low (0.0021 WL). The isotopic analysis of the thorium samples 7-S39-D and 7-S67-3 (Table 6), indicated that the equilibrium was undisturbed. Hence, the contamination is construed to be natural thorium.

Gamma spectral analysis of a water sample taken from the American Petroleum Institute (API) Oil Separator (7-W132, Table 5), revealed the presence of the radionuclide ^{110m} Ag in the suspended solids. The level of ^{110m}Ag activity reported, 12±5 pCi/g, is insignificant as a health hazard but could be indicative of BioMass Facilities sewer and drain contamination. The API Oil Separator is a device for removing oil from the effluent of the BioMass Facility drains and sewers prior to discharge into the Bureau of Mines sanitary sewer system.

Further investigation of this anomaly included gamma spectral analysis of four sludge samples (7-SS137 to 7-SS-140) and four water samples (7-W133 to 7-W136) retrieved from the Oil Separator by Bureau of Mines personnel, during the month of February 1983. These analyses indicated no ^{110m}Ag present (Table 5). Communication with the present director of the Bureau of Mines, Albany, and the former director of the BioMass Facility indicated that to their knowledge, the radionuclide ^{110m}Ag had not been used or available at either facility.

Since the sewer and drain lines of the BioMass Facility are, at present, immersed in the dump contaminants of the subsurface area, and a restriction is recommended for this subsurface area, it does not appear that any possible sewer contamination involving ^{110m}Ag will have a significant impact on any potential future remedial action.

It is our recommendation that the buildings and material associated with the BioMass Facility require no remedial action and are suitable for unrestricted use. Furthermore, since the exterior radiation stems from subsurface contamination, and the frequency of habitation is relatively low, there is no immediate hazard associated with site occupancy. However, the levels of subsurface contamination cannot be ignored and must be considered if any excavation is undertaken or if any change in usage for the property is contemplated.

Back Forty Area

The Back Forty area consists of a vacant field of approximately 14 acres with a relatively large contaminated area of about 0.8 acre. The radiological survey of this area revealed background radiation levels for surface alpha, beta-gamma, up to 9 k cts/min for low-energy x-ray and gamma, and up to 100 μR/h for the ambient radiation level at 3 ft. Since the radiation stems from subsurface contamination and the frequency of habitation in the area is relatively low, there is no immediate hazard associated with this area.

Subsurface investigation of the contaminated area revealed contamination consistent with the use of the area as a waste dump. The soil corings (i.e., 1-ft deep samples 7-S26 through 7-S32) revealed three corings (7-S26, 7-S31, and 7-S32) with essentially background levels. The contamination found in the other corings was as follows (elevated levels include background):

7-S27	BKGD ^{232}Th, 36 pCi/g ^{226}Ra, and 74 pCi/g uranium
7-S28	10 pCi/g ^{232}Th, 202 pCi/g ^{226}Ra, and 45 pCi/g uranium
7-S29	18 pCi/g ^{232}Th, 2 pCi/g ^{226}Ra, and 54 pCi/g uranium
7-S30	19 pCi/g ^{232}Th, 42 pCi/g ^{226}Ra, and 87 pCi/g uranium

The soil samples (sequential 1-ft samples to a depth of 10 ft designated 7-S56 through 7-S64 and 7-S73 through 7-S81) revealed the following information regarding the contamination.

- The largest source of contamination in the area was normal uranium (i.e. uranium that has been separated from its daughters). Levels of uranium up to 34 pCi/g were observed.

- The ^{232}Th decay chain and ^{226}Ra decay chain contaminations were generally low (i.e., about two or three times background) except for bore hole 7-S73 where the ^{232}Th decay chain reached 58 pCi/g at the 2-ft level and the ^{226}Ra decay chain reached 33 pCi/g at the 2-ft level. The uranium concentration was also 34 pCi/g in this sample, indicating that natural uranium contributed significantly as a source of this contamination.

- The contamination was concentrated in the top 4-ft region although contamination was observed at the 9-ft depth (7-S57-9).

- The four holes identified as 7-S77 through 7-S80 (see Fig. 6) showed background levels for all suspected contaminants.

These results indicate that the contamination is subsurface, occurring primarily in the first 4-ft, although some contamination was observed as deep as 9-ft. It is composed largely of natural uranium and natural thorium, with lesser amounts of normal uranium. The isotopic analyses of the thorium samples (7-S28-C and 7-S73-2, Table 6) indicated that the equilibrium was undisturbed. Hence the contamination was construed as natural thorium. The mesothorium chain (^{228}Ra, ^{228}Ac, ^{228}Th) has not been specifically identified in this area of the Bureau of Mines site.

The water sample (7-W88) taken from bore hole 7-S73 (with the highest level of contamination in the Back Forty area) did not show abnormal levels of radioactivity. However, this should not be construed as evidence of stability of the contamination. Since the watertable in the area seems to overlap the contamination, the possibility of subsurface lateral migration cannot be ruled out.

Each bore hole was logged with a 2-in x 2-in NaI(Tℓ) detector prior to backfilling. Levels of radiation from the soil surrounding the bore hole, if larger than those found in the bore hole samples, would result in significantly elevated readings from the logged gamma-ray spectrum. No such elevated levels were observed. Hence conclusions regarding the source of the contamination and the concentration were restricted to the more sensitive radiochemical analyses of split-spoon samples taken from the bore holes (Table 4).

The levels of radiation in the Back Forty area do not constitute an immediate health hazard; however, any excavating work done in this area should take into consideration the presence of this contamination and should be accompanied by appropriate health physics surveillance. Furthermore, the possibilities of subsurface lateral migration of the contamination cannot be ruled out since the groundwater level overlaps the contamination. Hence, it is our recommendation that while the present use of the property does not pose any health hazard, some remedial action would be required if any changes in the usage of the property were contemplated.

REFERENCES

1. U.S. Department of Energy. 1981. "Requirements for Radiation Protection." DOE 5480.1, Chapter XI.

2. U.S. Department of Health, Education and Welfare. 1970. "Radiological Health Handbook." Bureau of Radiological Health, Rockville, MD.

3. U.S. Nuclear Regulatory Commission. 1981. "Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel Cycle Facilities." Vol. III. ORNL/NUREG/TM-190/V3. Prepared by Oak Ridge National Laboratory.

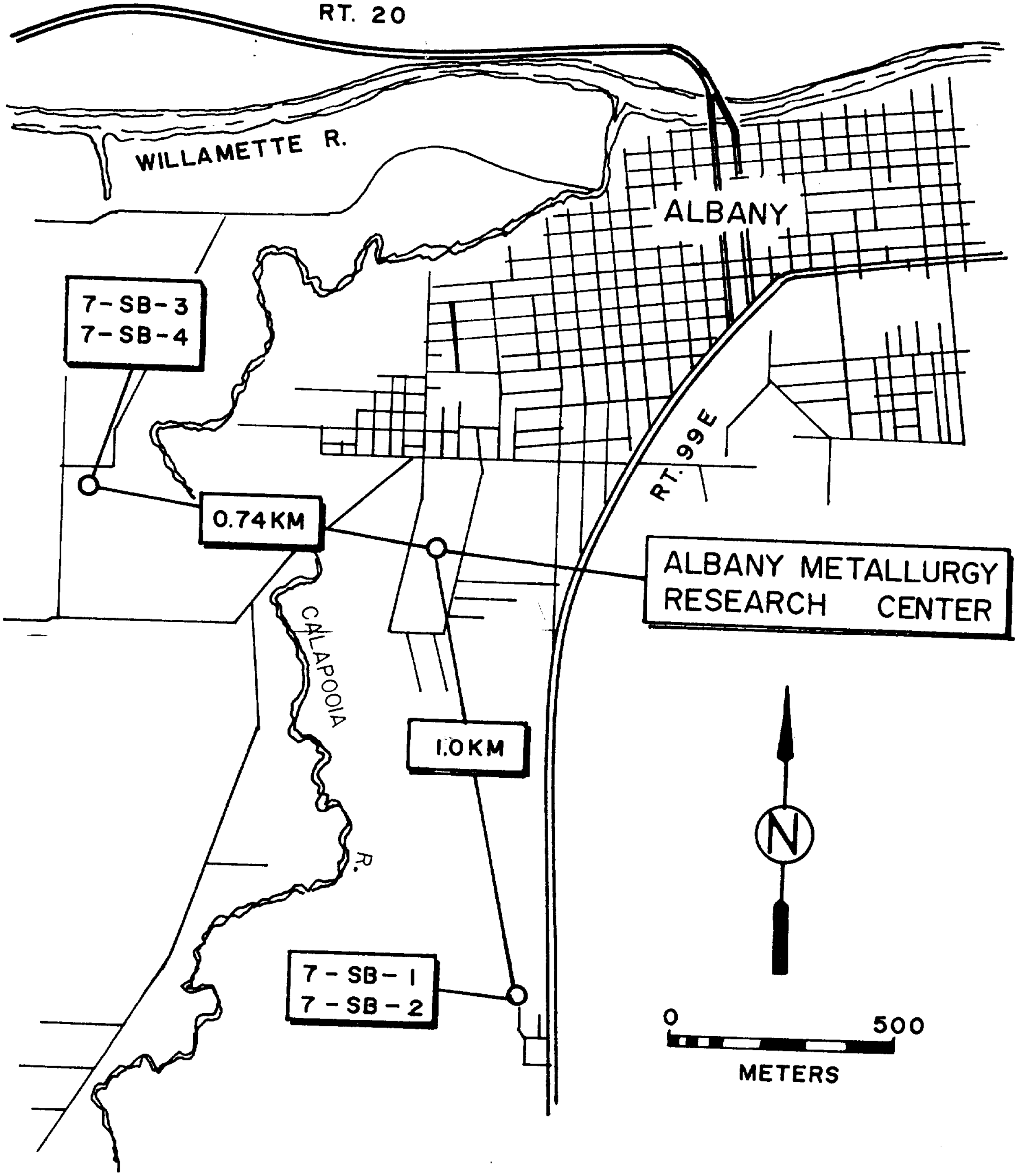


Fig. 1. Albany Metropolitan Area with Background Soil Coring Locations

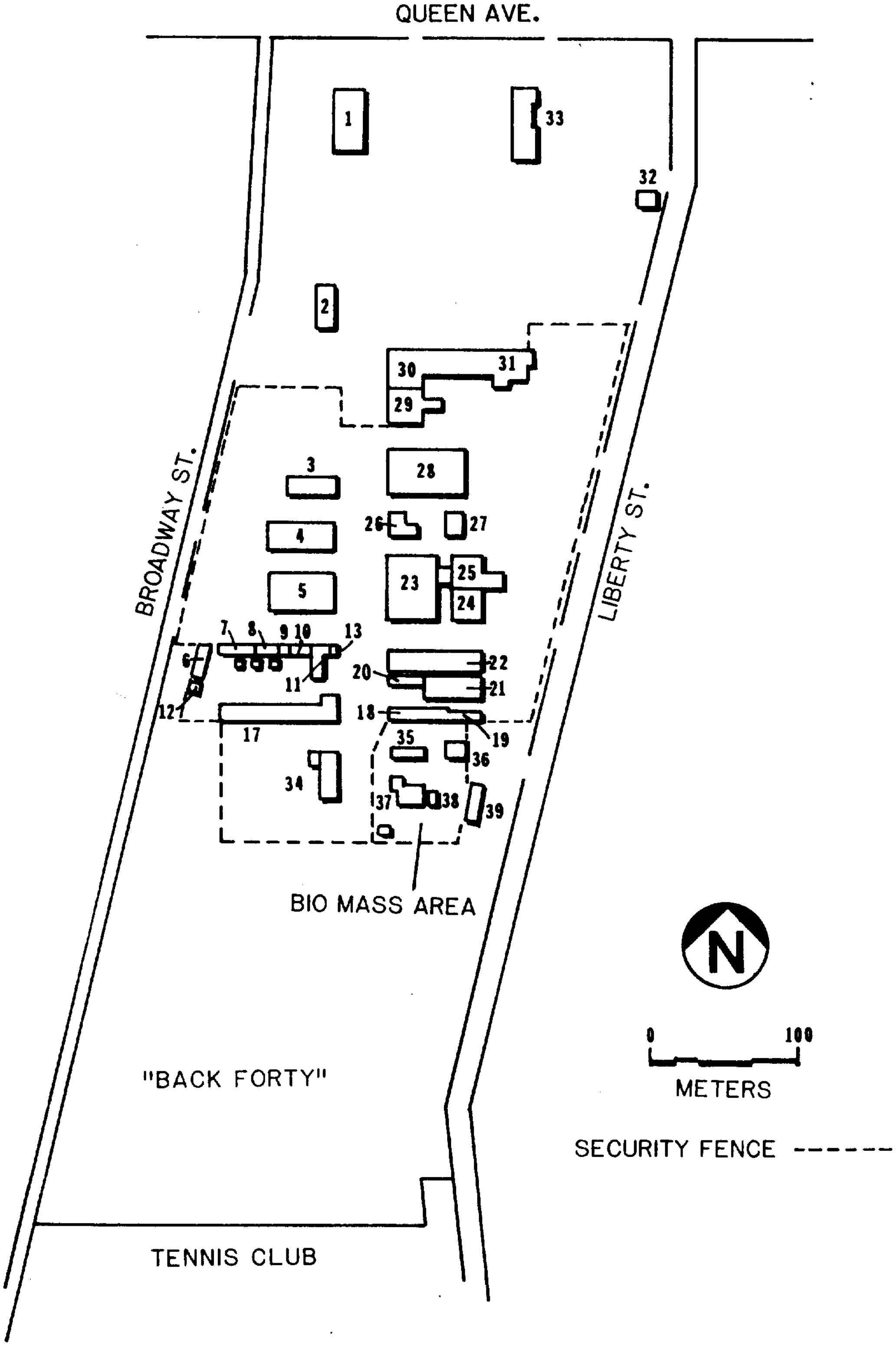


Fig. 2. Albany Metallurgical Research Center Site

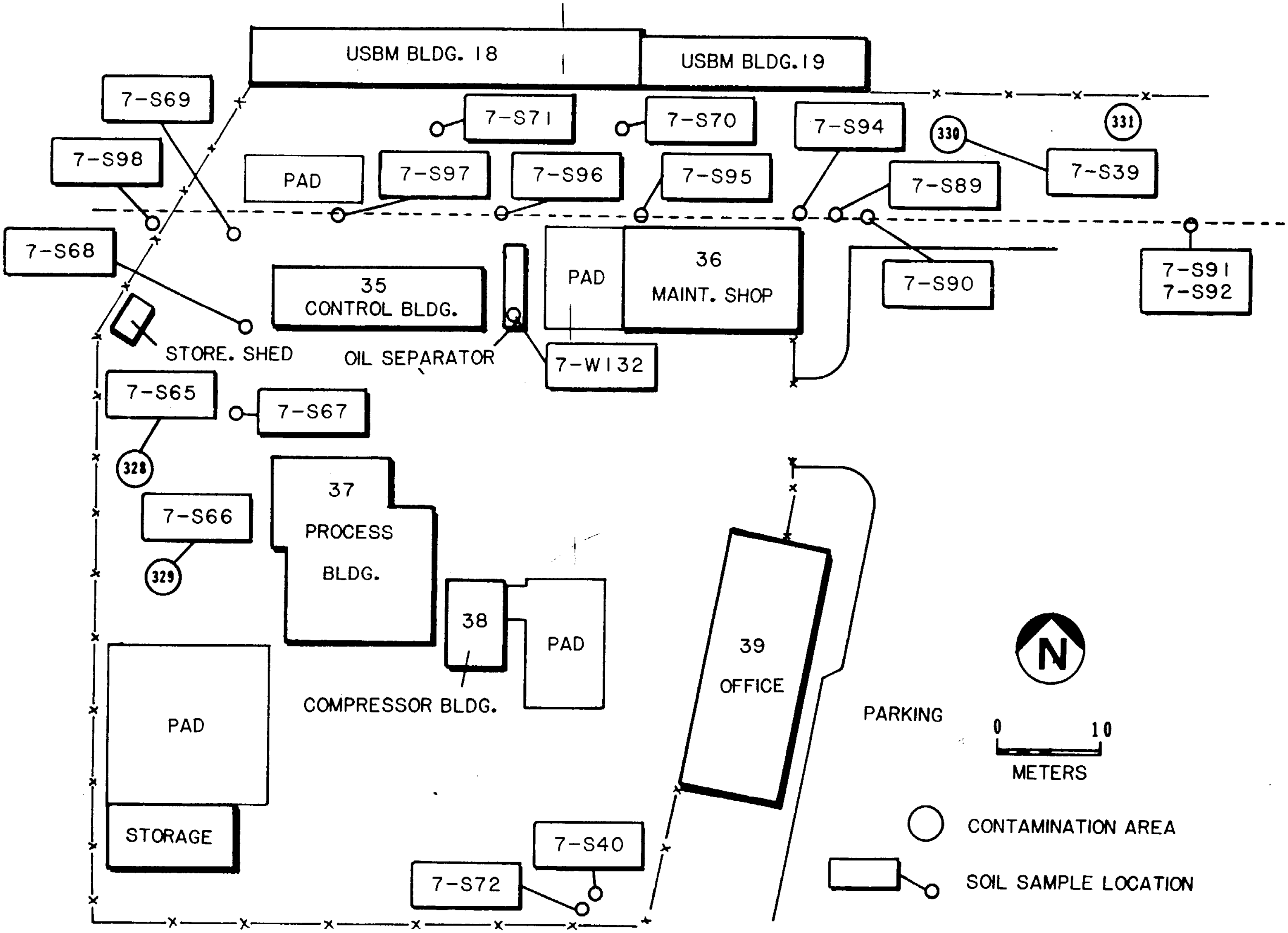


Fig. 3. BioMass Facility Site with Contamination Locations and Soil Sample Locations

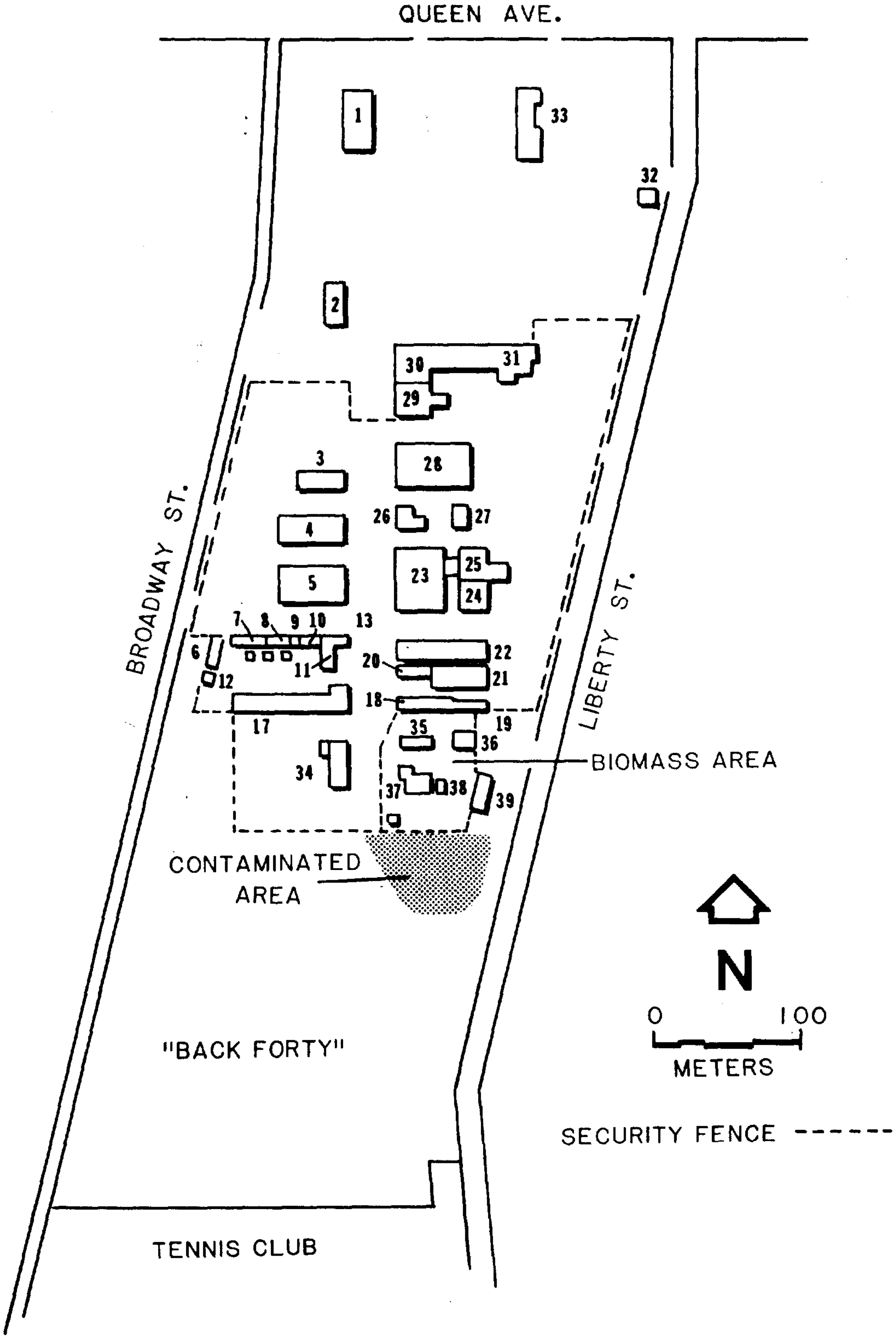


Fig. 4. "Back Forty" Site

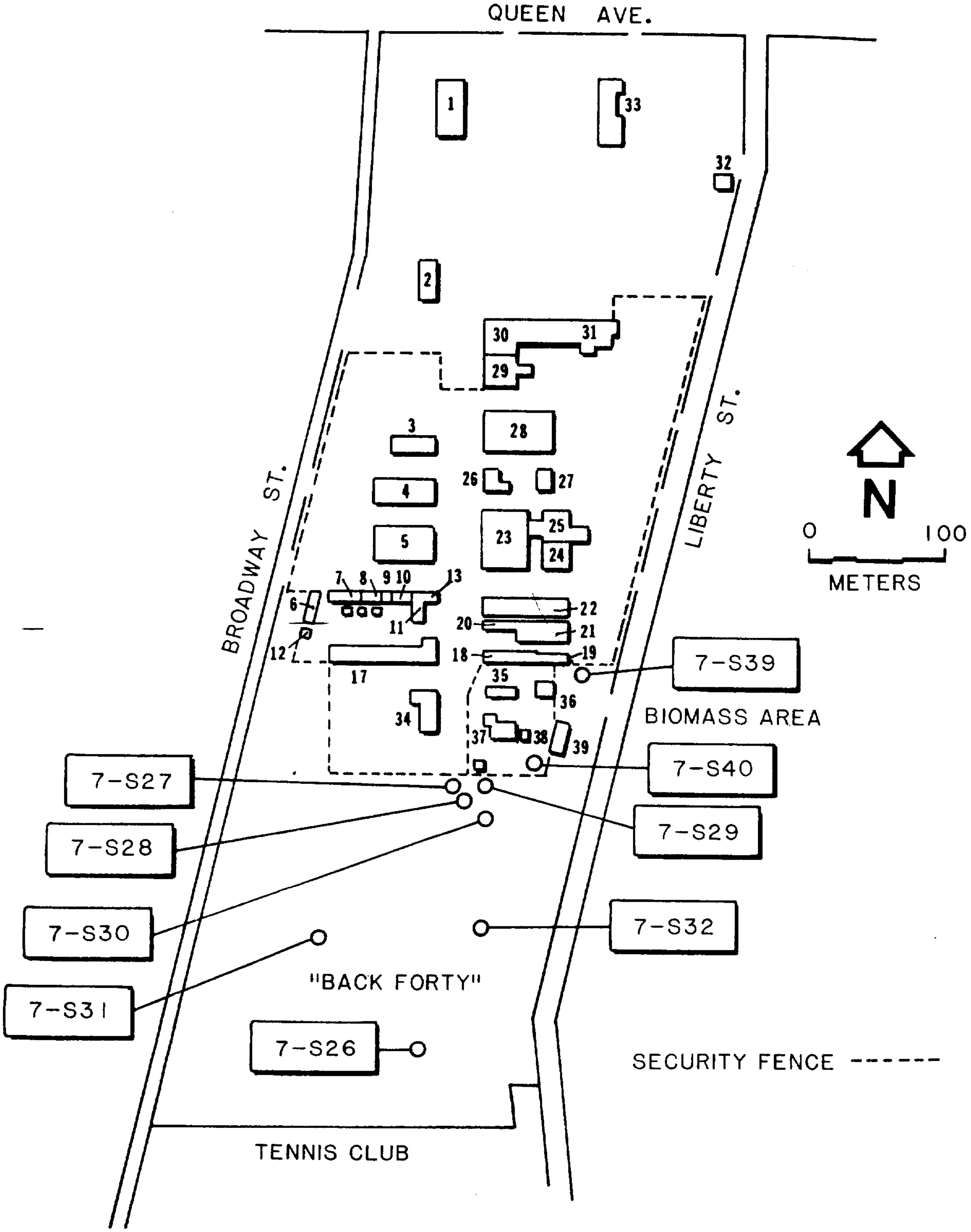


Fig. 5. Soil Coring Locations

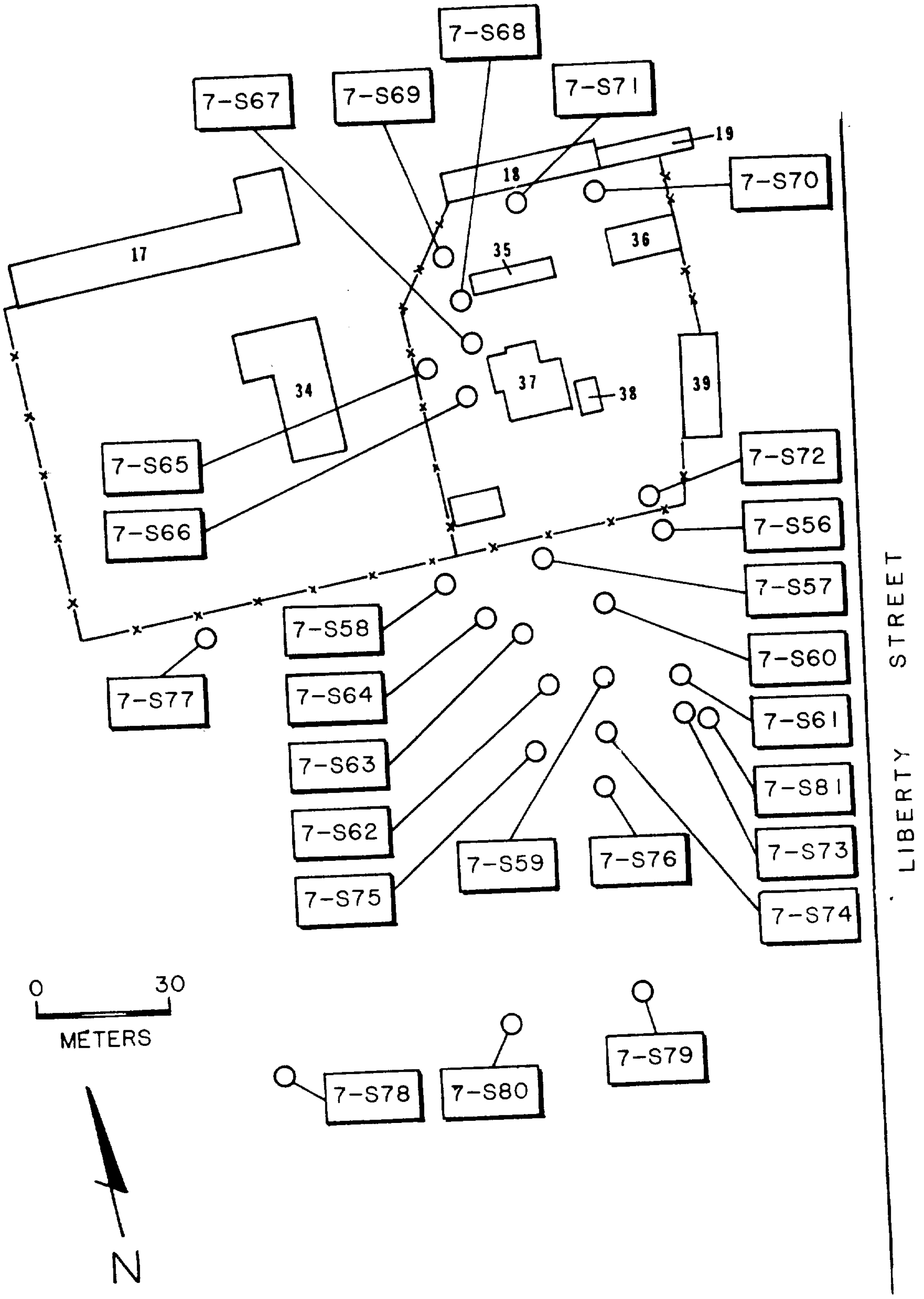


Fig. 6. Soil Boring Locations

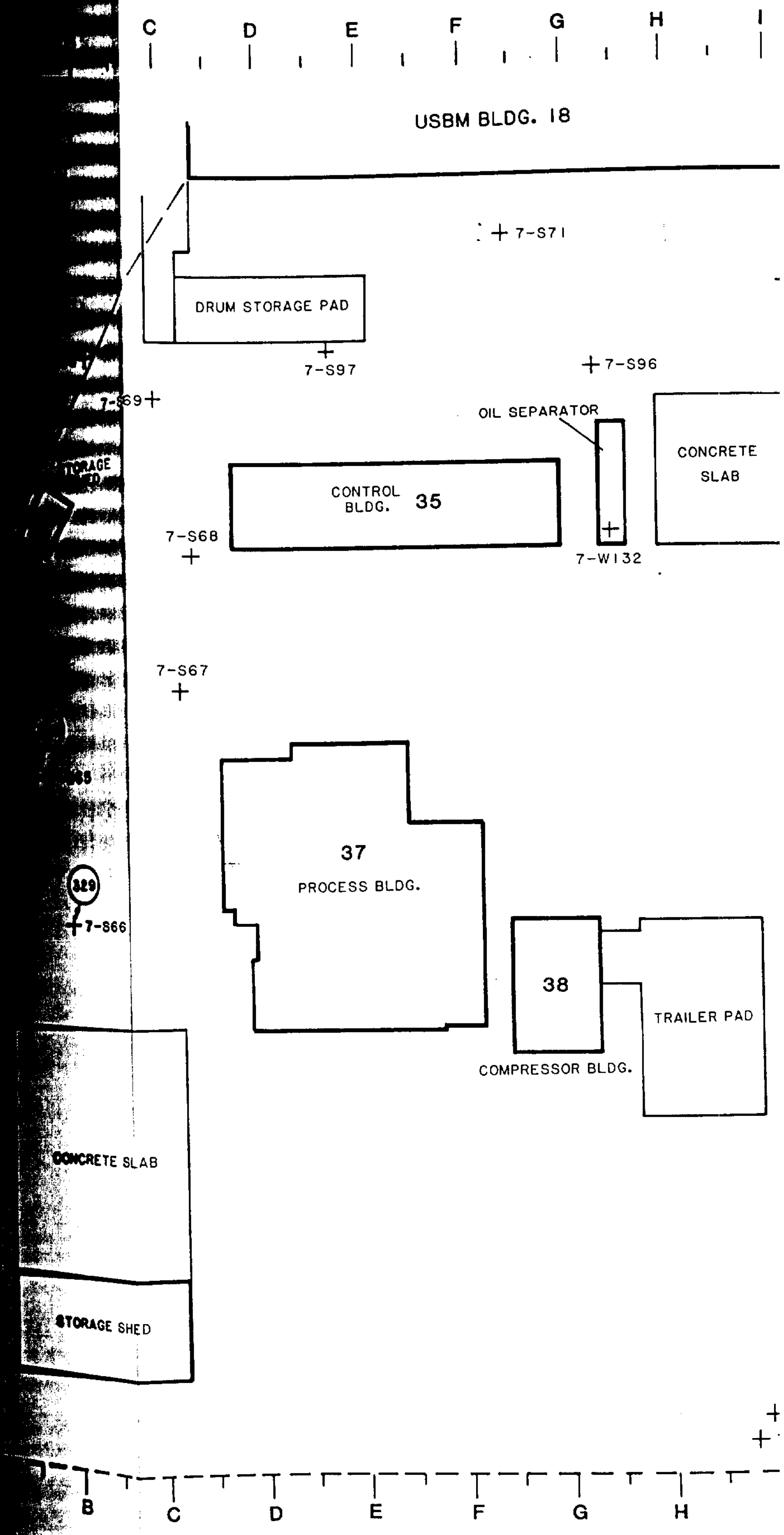
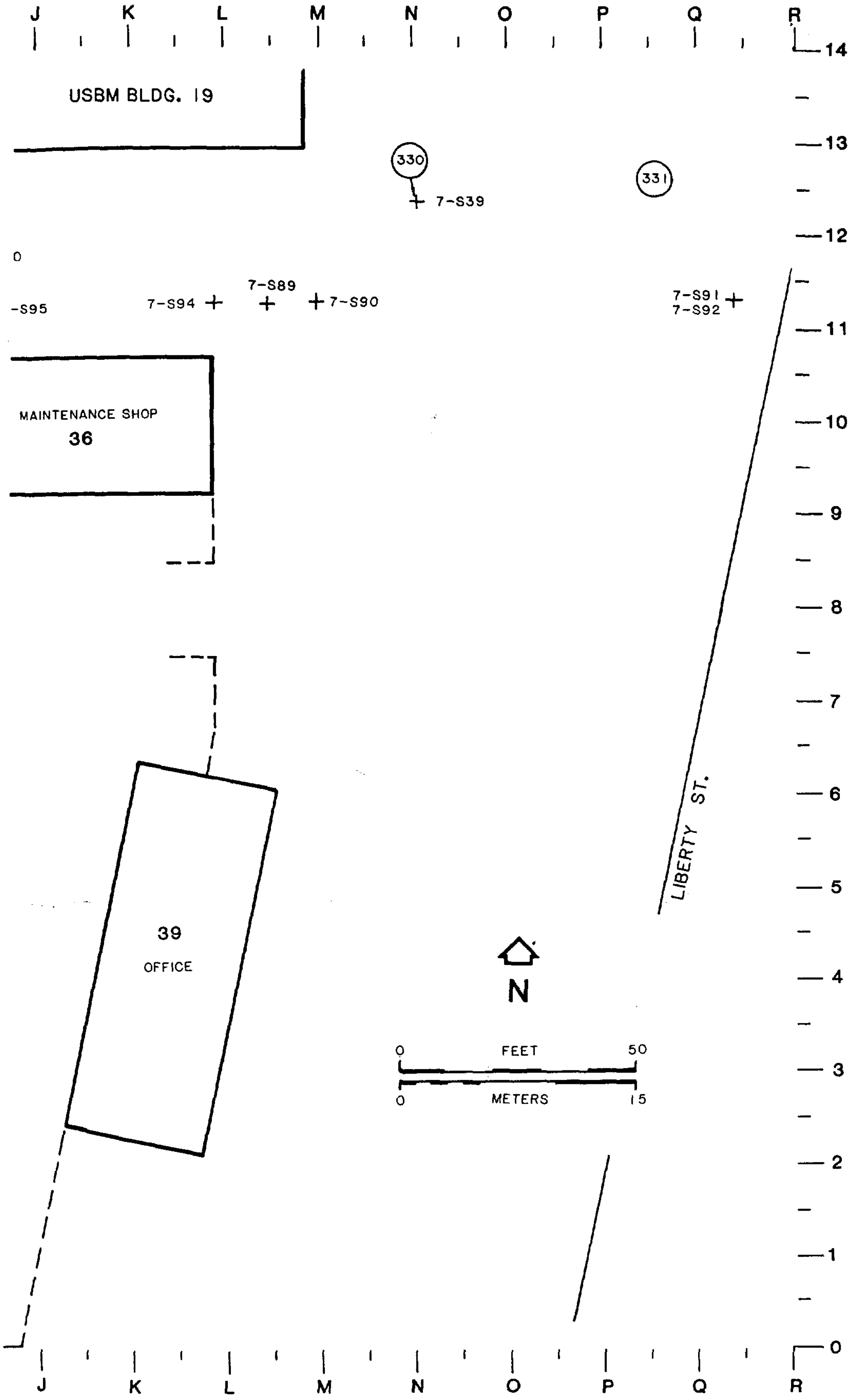
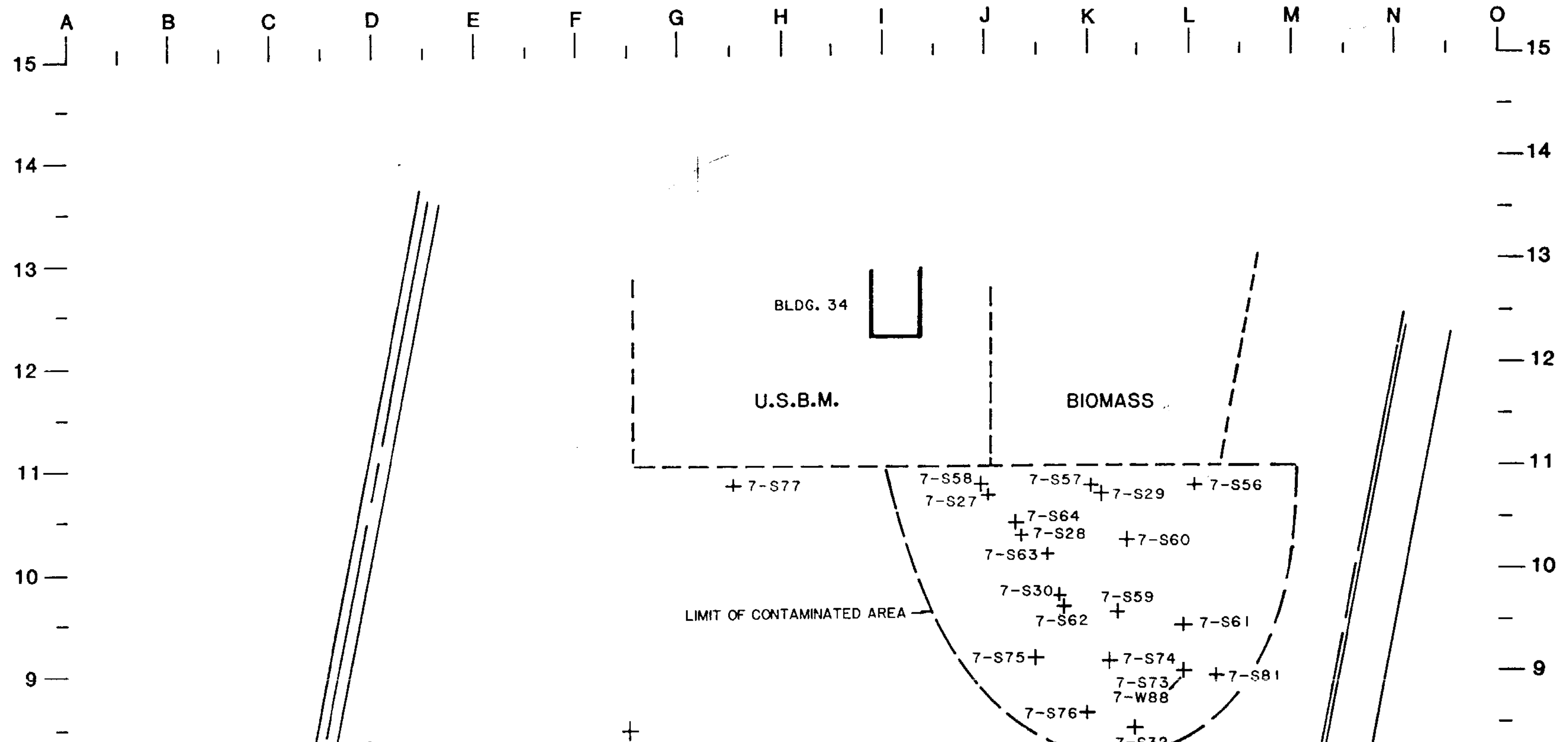


Fig. 7. BioMass



lity Working Drawing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BLDG. 34
U.S.B.M.
BIOMASS
LIMIT OF CONTAMINATED AREA
7-S77
7-S58
7-S27
7-S57
7-S29
7-S56
7-S64
7-S28
7-S60
7-S63
7-S30
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7-S73
7-W88
7-S81
7-S76

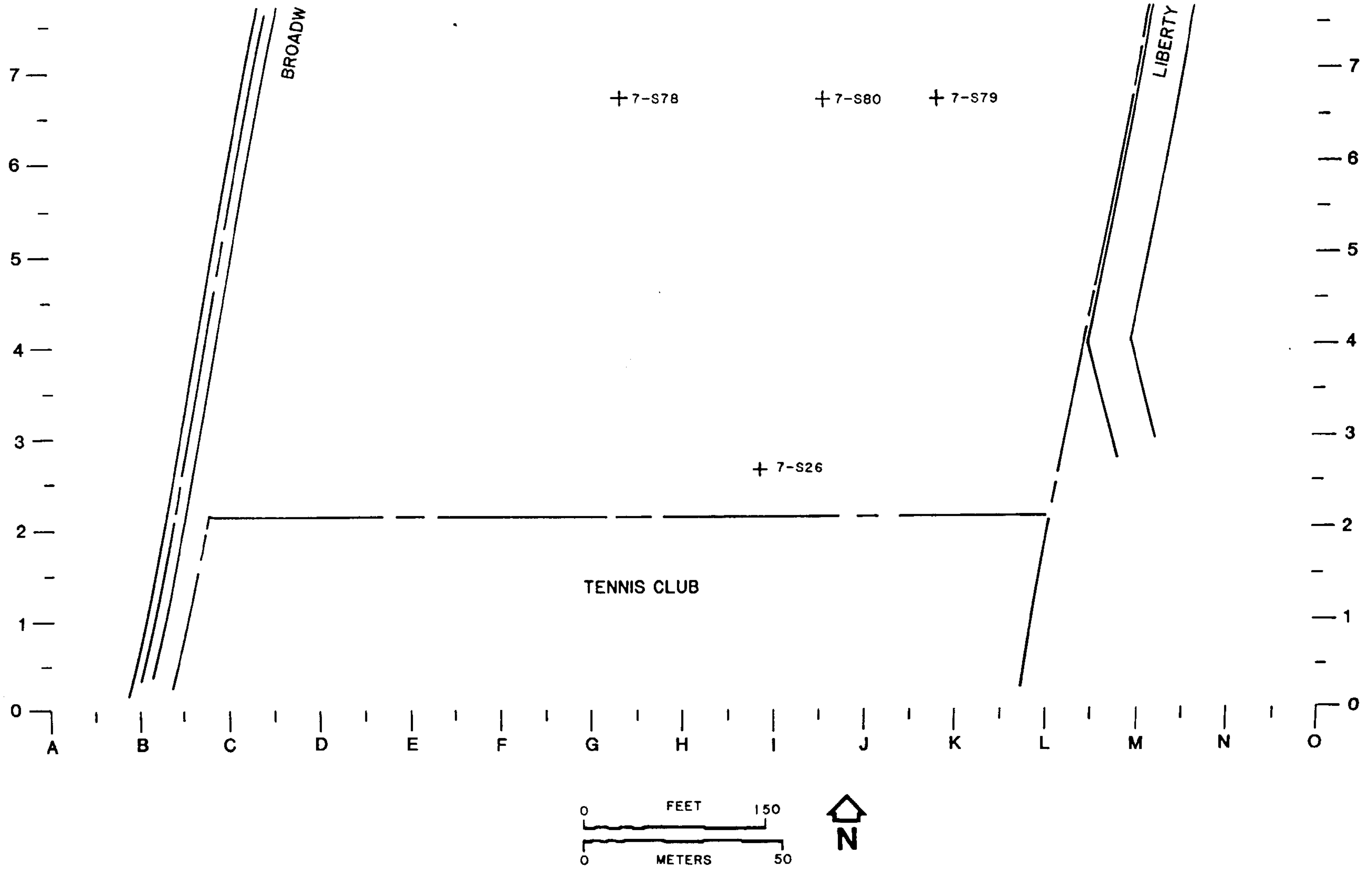

Fig. 8. "Back Forty" Site Working Drawing

TABLE 1

INSTRUMENT SURVEY RESULTS CONTAMINATED AREAS AND BUILDINGS

(See Figure 3 and Figure 4)

Location	Surface αβγ[a,b] (cts/min-51 cm²)		Low-Energy x and γ[b,c] (cts/min)	Ambient Radiation Levels[b,d] (μR/h @ 3 ft)	
	Beta	Alpha		PRM-7	RSS-111
BioMass[e]					
328	25 k	BKGD	10 k	12	15
329	25 k	BKGD	35 k	10	30
330	BKGD	BKGD	20 k	50	-
331	BKGD	BKGD	5 k	11	-
Building Interior	BKGD	BKGD	BKGD	BKGD	8-9
Back Forty[f]					
0.8 acre area	BKGD	BKGD	9 k	100	32.8

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[a] The Beta Mode Direct Readings and Alpha Mode Direct Readings were taken with PAC-4G-3 instruments. The beta mode detects both electromagnetic and particulate radiation. If an area indicated a higher count rate than the instrument background, a beta mode reading was obtained. The instrument was then switched to the alpha mode, and a reading of the alpha contamination was obtained. In the alpha mode the instrument only responds to particles with high-specific ionization, such as alpha particles. If no contamination was detected in the beta mode, no alpha mode survey was necessary. The beta mode readings are corrected for any alpha contribution by subtracting the alpha mode reading from the beta mode reading (see Appendix 1).

[b] The direct measurement results are gross readings. Background radiation levels have not been subtracted nor have conversion factors been applied for specific radioisotopes. The background radiation levels, as interpreted from measurements made in the general area, are as follows:

PAC-4G-3	200 cts/min-51 cm² (beta) 50 cts/min-51 cm² (alpha)
PRM-5-3	500 cts/min
PRM-7	7 μR/h

TABLE 1
(cont'd.)

INSTRUMENT SURVEY RESULTS CONTAMINATED AREAS AND BUILDINGS

[c] Measurements based on PRM-5-3 survey meter readings (see Appendix 1).

[d] Measurements made with both PRM-7 μR survey meters (differential readings) and Reuter Stokes (RSS-111) fixed position meters (integral readings). For detailed information on these measuring instruments see Appendix 1.

[e] BioMass Facility contaminated areas and building interiors (see Fig. 3).

[f] Back Forty contaminated area in vacant field (see Fig. 4) - maximum meter readings.

TABLE 2

WORKING LEVEL and RADON CONCENTRATIONS

Location	WL[a]	Radon (pCi/ℓ)	Thoron (pCi/ℓ)	Actinon (pCi/ℓ)
BioMass Facility				
Building 35	0.0094	0.94	0.0064	BDL[b]
Building 36	0.0005	0.05	0.0022	BDL
Building 39	0.0044	0.44	0.0070	BDL
Outside	0.0021	0.21	–	–

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[a] A Working Level (WL) is defined in 10 CFR 712 as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The numerical value of the WL is derived from the alpha energy released by the total decay through RaC' of the short-lived radon daughter products, RaA, RaB, and RaC at radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air.

[b] Below Detectable Level.

TABLE 3

SOIL-SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
		BACKGROUND SOIL CORINGS		
7-SB-1A	470	389	368	0
7-SB-1B	589	509	458	12
7-SB-1C	660	577	520	39
7-SB-1D	1559	1363	905	436
7-SB-2A	575	468	419	32
7-SB-2B	551	468	422	17
7-SB-2C	767	658	622	13
7-SB-2D	1891	1603	1132	459
7-SB-3A	463	374	346	12
7-SB-3B	565	476	384	31
7-SB-3C	795	683	567	108
7-SB-3D	2160	1835	1258	559
7-SB-4A	570	500	468	16
7-SB-4B	618	536	509	9
7-SB-4C	626	549	480	43
7-SB-4D	1883	1618	1283	324
		SITE SOIL CORINGS		
7-S-26A	652	580	524	48
7-S-26B	443	403	375	17
7-S-26C	623	566	505	55
7-S-26D	2030	1860	1131	695
7-S-27A	722	684	390	288
7-S-27B	1113	1027	593	430
7-S-27C	1207	1116	624	487
7-S-27D	3011	2633	1238	1379
7-S-28A	783	711	513	190
7-S-28B	850	774	542	225
7-S-28C	1026	910	572	332
7-S-28D	2842	2448	1165	1271

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S-29A	334	315	131	181
7-S-29B	699	643	461	176
7-S-29C	1335	1226	729	487
7-S-29D	3142	2858	1477	1363
7-S-30A	889	848	662	178
7-S-30B	1050	995	663	324
7-S-30C	1204	1059	579	476
7-S-30D	3226	2631	1177	1446
7-S-31A	387	359	338	13
7-S-31B	509	468	449	9
7-S-31C	683	624	598	16
7-S-31D	2362	2157	1147	975
7-S-32A	317	294	233	53
7-S-32B	422	393	329	56
7-S-32C	1128	1034	786	240
7-S-32D	2523	2320	1297	1012
7-S-39A	692	530	220	302
7-S-39B	695	562	241	312
7-S-39C	842	735	226	499
7-S-39D	1725	1511	670	835
7-S-40A	565	437	272	158
7-S-40B	636	492	324	164
7-S-40C	852	656	418	231
7-S-40D	2404	1820	820	991
		SOIL BORINGS		
7-S56-1	377	339	233	98
7-S56-2	362	303	258	40
7-S56-3	480	387	198	181
7-S56-4	450	362	122	223
7-S56-5	426	352	214	133
7-S56-6	545	526	322	198
7-S56-7	735	603	429	167
7-S56-8	744	653	307	342
7-S56-9	795	661	483	167
7-S56-10	579	457	295	156

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S57-1	305	278	197	72
7-S57-2	274	242	204	26
7-S57-3	349	303	187	107
7-S57-4	153	128	103	10
7-S57-7	166	138	116	6
7-S57-8	970	767	546	210
7-S57-9	759	642	354	278
7-S57-10	467	363	306	45
7-S58-1	386	343	263	74
7-S58-2	312	270	238	18
7-S58-3	560	478	404	65
7-S58-4	164	136	119	1
7-S58-5	584	478	401	66
7-S58-6	616	490	453	21
7-S58-7	767	581	553	7
7-S58-8	587	458	391	55
7-S58-9	554	429	353	65
7-S58-10	276	235	114	105
7-S59-1	605	486	360	121
7-S59-2	302	245	185	27
7-S59-3	493	399	338	49
7-S59-4	482	388	308	75
7-S59-5	441	352	275	67
7-S59-6	714	551	389	148
7-S59-7	639	505	396	101
7-S59-8	443	363	242	113
7-S59-9	527	458	211	241
7-S59-10	273	221	181	33
7-S60-1	327	287	229	47
7-S60-2	289	257	210	28
7-S60-3	366	322	274	39
7-S60-4	374	318	277	25
7-S60-5	378	314	193	103
7-S60-6	588	479	345	125
7-S60-7	829	632	607	15
7-S60-8	674	533	454	68
7-S60-9	632	550	319	217
7-S60-10	213	175	127	29

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S61-1	310	281	170	104
7-S61-2	525	441	332	102
7-S61-3	411	326	271	43
7-S61-4	523	413	323	84
7-S61-5	98	77	49	6
7-S61-6	337	279	168	99
7-S61-7	743	605	428	164
7-S61-8	577	461	376	77
7-S61-9	250	213	132	71
7-S61-10	763	639	426	201
7-S62-1	489	402	329	62
7-S62-2	609	499	387	101
7-S62-3	344	292	221	57
7-S62-4	29	25	12	13
7-S62-5	699	541	429	103
7-S62-6	702	538	437	92
7-S62-7	690	522	465	37
7-S62-8	744	550	494	39
7-S62-9	505	434	209	217
7-S62-10	770	650	319	324
7-S63-1	386	349	252	92
7-S63-2	30	27	13	14
7-S63-5	189	157	136	6
7-S63-6	135	106	50	47
7-S63-7	185	158	97	40
7-S63-8	664	540	442	90
7-S63-9	883	725	550	162
7-S63-10	1008	783	669	102
7-S64-1	332	299	251	33
7-S64-2	365	324	288	19
7-S64-3	58	52	27	22
7-S64-6	408	320	279	24
7-S64-7	627	478	452	12
7-S64-8	619	470	448	9
7-S64-9	325	255	206	31
7-S64-10	565	428	391	23

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S65-1	479	402	321	69
7-S65-2	437	360	314	29
7-S65-3	499	418	354	54
7-S65-4	475	383	333	45
7-S65-5	739	572	515	42
7-S65-6	310	257	200	49
7-S65-7	172	135	112	4
7-S65-8	678	534	448	77
7-S65-9	880	718	504	205
7-S65-10	761	613	493	107
7-S66-1	39	38	6	30
7-S66-3	202	176	108	47
7-S66-4	227	202	113	81
7-S66-5	653	508	414	82
7-S66-6	534	441	270	163
7-S66-7	256	213	142	63
7-S66-8	797	646	405	229
7-S66-9	765	616	455	153
7-S66-10	328	261	239	14
7-S67-1	441	397	282	107
7-S67-2	394	333	246	77
7-S67-3	493	316	246	60
7-S67-4	536	408	366	19
7-S67-5	537	406	377	9
7-S67-6	581	472	363	99
7-S67-7	811	643	576	57
7-S67-8	853	701	526	167
7-S67-9	897	729	540	183
7-S67-10	835	700	495	197
7-S68-1	409	357	240	110
7-S68-2	332	279	225	46
7-S68-3	252	116	113	43
7-S68-4	778	541	320	209
7-S68-5	657	512	421	85
7-S68-6	838	661	524	130
7-S68-7	771	642	423	213
7-S68-8	677	584	330	245
7-S68-9	165	140	113	17
7-S68-10	1149	929	675	248

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S69-1	337	295	157	132
7-S69-2	228	211	70	1245
7-S69-3	224	200	65	112
7-S69-4	561	467	317	141
7-S69-5	760	661	395	253
7-S69-6	603	492	363	118
7-S69-7	613	510	345	154
7-S69-8	678	548	379	159
7-S69-9	449	351	306	33
7-S69-10	1128	919	725	189
7-S70-1	305	259	197	51
7-S70-2	685	605	479	119
7-S70-3	387	331	291	32
7-S70-4	715	544	459	76
7-S70-5	689	558	431	119
7-S70-6	653	536	408	124
7-S70-7	802	650	539	99
7-S70-8	770	589	492	86
7-S70-9	752	574	359	194
7-S70-10	911	667	491	155
7-S71-1	465	436	249	157
7-S71-2	440	399	345	39
7-S71-3	605	534	357	162
7-S71-4	824	705	517	173
7-S71-5	789	661	411	230
7-S71-6	686	582	416	148
7-S71-7	285	256	186	49
7-S71-8	770	634	267	340
7-S71-9	853	694	208	419
7-S71-10	799	660	246	389
7-S72-1	421	373	245	112
7-S72-2	323	282	206	58
7-S72-3	215	188	136	29
7-S72-4	428	362	228	118
7-S72-6	912	698	458	221
7-S72-7	724	610	381	212
7-S72-8	780	668	441	209
7-S72-9	363	309	249	41
7-S72-10	1053	862	564	281

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S73-1	271	255	196	39
7-S73-2	320	299	172	104
7-S73-3	468	416	238	150
7-S73-4	588	420	210	202
7-S73-5	768	628	306	316
7-S73-6	607	492	378	110
7-S73-7	657	586	245	335
7-S73-8	640	559	228	316
7-S73-9	814	688	379	306
7-S73-10	466	369	219	148
7-S74-1	284	254	199	46
7-S74-2	198	173	137	30
7-S74-5	345	271	237	30
7-S74-6	712	568	380	180
7-S74-7	556	446	364	77
7-S74-8	517	388	317	67
7-S74-9	377	332	149	179
7-S74-10	442	384	143	238
7-S75-1	363	311	278	31
7-S75-2	334	297	275	22
7-S75-3	307	262	221	36
7-S75-4	12	19	8	5
7-S75-5	369	288	238	48
7-S75-6	841	678	446	228
7-S75-7	639	479	437	39
7-S75-8	869	649	567	79
7-S75-9	114	99	60	35
7-S75-10	821	638	471	165
7-S76-1	379	317	249	61
7-S76-2	351	300	192	102
7-S76-3	427	355	259	90
7-S76-4	654	539	373	162
7-S76-5	603	459	424	28
7-S76-6	821	659	498	151
7-S76-7	591	450	365	79
7-S76-8	892	672	546	124
7-S76-9	387	329	157	124

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S77-1	407	334	312	13
7-S77-2	388	323	279	39
7-S77-3	499	376	281	88
7-S77-4	686	515	499	7
7-S77-5	568	440	398	36
7-S77-6	721	532	458	68
7-S77-7	600	466	360	100
7-S77-8	671	530	421	102
7-S77-9	211	179	115	62
7-S77-10	95	76	68	3
7-S78-1	242	213	203	3
7-S78-2	406	362	350	11
7-S78-3	403	329	307	16
7-S78-4	580	455	424	26
7-S78-5	681	538	517	15
7-S78-6	629	482	455	20
7-S78-7	812	645	569	68
7-S78-8	577	461	451	7
7-S78-9	727	580	503	71
7-S78-10	712	557	535	16
7-S79-1	296	265	233	27
7-S79-2	359	302	151	141
7-S79-3	432	350	220	123
7-S79-4	654	526	411	110
7-S79-5	680	526	394	121
7-S79-6	537	421	312	99
7-S79-7	567	459	368	80
7-S79-8	651	523	455	58
7-S79-9	674	555	501	48
7-S79-10	679	548	466	75
7-S80-1	362	323	305	11
7-S80-2	365	309	177	118
7-S80-3	377	309	102	167
7-S80-4	573	454	375	73
7-S80-5	559	426	393	23
7-S80-6	320	241	209	4
7-S80-7	482	360	350	8
7-S80-8	552	426	328	96
7-S80-9	476	377	359	15
7-S80-10	867	695	568	124

TABLE 3
(cont'd.)

SOIL SAMPLE WEIGHTS
(grams)

Sample No.	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
7-S81-1	184	168	94	63
7-S81-2	391	320	259	58
7-S81-3	473	384	313	65
7-S81-4	579	440	203	221
7-S81-5	610	492	265	223
7-S81-6	727	587	404	175
7-S81-7	458	368	297	60
7-S81-8	627	536	254	275
7-S81-9	600	480	382	91
7-S81-10	684	531	495	32
AUXILIARY SAMPLES (per USBM)				
7-S89-3	225	219	180	33
7-S90-3	323	316	204	108
7-S91-3	229	224	193	22
7-S92-1	249	246	154	91
7-S94	79	77	30	47
7-S95	90	85	38	47
7-S96	81	78	33	45
7-S97	80	78	42	35
7-S98	85	83	40	42

TABLE 4

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

(See Figures 1, 3, 5, 6, 7, and 8)

Sample[a] No.	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±σ	pCi/g±σ
		BACKGROUND SOIL CORINGS			
7-SB1-A	1.64±0.08	0.80±0.12	0.68±0.08	1.6± 1.0	1.1± 0.7
7-SB1-B				3.5± 1.0	2.4± 0.7
7-SB1-C				2.3± 1.1	1.6± 0.8
7-SB1-D				2.8± 1.4	2.0± 1.0
7-SB2-A	0.95±0.05	0.81±0.08	0.84±0.15	2.6± 1.2	1.8± 0.8
7-SB2-B				0.6± 0.96	0.4± 0.7
7-SB2-C				2.0± 1.2	1.4± 0.8
7-SB2-D				1.1± 1.2	0.8± 0.8
7-SB3-A	1.38±0.07	1.12±0.12	0.83±0.07	4.2± 1.3	2.9± 0.9
7-SB3-B				1.7± 1.3	1.2± 0.9
7-SB3-C				0.9± 1.3	0.6± 0.9
7-SB3-D				1.5± 1.4	1.0± 1.0
7-SB4-A	0.85±0.08	1.19±0.20	0.93±0.13	2.4± 1.4	1.7± 1.0
7-SB4-B				2.3± 1.3	1.6± 0.9
7-SB4-C				2.8± 1.3	2.0± 0.9
7-SB4-D				4.0± 1.2	2.8± 0.8
		SITE SOIL CORINGS			
7-S26-A	0.44±0.05	0.99±0.12	0.65±0.07	3.1± 1.3	2.2± 0.9
7-S26-B				2.1± 1.2	1.5± 0.8
7-S26-C				1.9± 1.3	1.3± 0.9
7-S26-D				4.0± 1.3	2.8± 0.9
7-S27-A	0.06±0.03	0.69±0.05	34.6 ± 2.4	91 ± 9.1	64.0± 6.4
7-S27-B	0.05±0.02	0.86±0.06	36.3 ± 2.5	95 ± 9.5	66 ± 6.6
7-S27-C	0.06±0.03	0.62±0.04	35.8 ±2 .5	106 ±10.6	74 ± 7.4
7-S27-D	0.15±0.04	1.30±0.09	10.8 ± 0.8	29 ± 2.9	20 ± 2.0
7-S28-A	0.11±0.03	3.37±0.24	8.26± 0.58	27 ± 2.7	19 ± 1.9
7-S28-B	<0.03	2.68±0.19	21.5 ± 1.5	62 ± 6.2	43 ± 4.3
7-S28-C	0.42±0.03	101 ±7	22.2 ± 1.6	64 ± 6.4	45 ± 4.5
7-S28-D	0.23±0.04	73.7 ±5.2	6.34± 0.44	24 ± 2.4	17 ± 1.7

TABLE 4
(cont'd.)

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

No.	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±σ	pCi/g±σ
SOIL CORINGS - (cont'd.)					
7-S29-A	0.24±0.04	4.26± 0.30	1.47± 0.10	19 ± 1.9	13 ± 1.3
7-S29-B	0.34±0.03	7.02± 0.49	1.83± 0.13	55 ± 5.5	38 ± 3.8
7-S29-C	0.43±0.03	8.98± 0.63	1.76± 0.12	77 ± 7.7	54 ± 5.4
7-S29-D	0.37±0.03	7.63± 0.53	1.80± 0.13	55 ± 5.5	38 ± 3.8
7-S30-A	<0.03	0.69± 0.05	42.3 ± 3.0	124 ±12.4	87.0± 8.7
7-S30-B	0.41±0.03	3.16± 0.22	37.4 ± 2.6	70 ± 7.0	49.0± 4.9
7-S30-C	1.32±0.09	9.44± 0.66	10.4 ± 0.7	44 ± 4.4	31.0± 3.1
7-S30-D	0.26±0.04	4.16± 0.29	2.20± 0.15	25 ± 2.5	17.0± 1.7
7-S31-A	0.37±0.03	1.16± 0.08	1.25± 0.09	1.7± 0.17	1.2± 0.12
7-S31-B	0.36±0.03	1.24± 0.09	1.41± 0.10	2.0± 0.2	1.4± 0.14
7-S31-C	0.30±0.04	1.26± 0.09	1.53± 0.11	1.6± 0.16	1.0± 0.1
7-S31-D	0.15±0.04	0.78± 0.05	0.61± 0.04	2.1± 0.21	1.5± 0.15
7-S32-A	0.41±0.03	1.14± 0.08	1.07± 0.08	1.6± 0.16	1.1± 0.11
7-S32-B	0.31±0.04	1.16± 0.08	1.41± 0.±0	1.6± 0.16	1.1± 0.11
7-S32-C	0.27±0.04	1.14± 0.08	1.30± 0.09	1.5± 0.15	1.0± 0.1
7-S32-D	0.11±0.03	1.05± 0.07	1.39± 0.10	1.5± 0.15	1.0± 0.1
7-S39-A	0.11±0.02	2.81± 0.20	1.63± 0.11	4.2± 0.42	2.9± 0.29
7-S39-B	<0.03	2.99± 0.21	1.00± 0.07	3.5± 0.35	2.4± 0.24
7-S39-C	0.16±0.04	94.1 ± 7.0	12.5 ± 0.9	4.1± 0.41	2.9± 0.29
7-S39-D	<0.03	1850.0 ±90	166.0 ±12	22.0± 2.2	15.0± 1.5
7-S40-A	0.15±0.04	2.21± 0.15	1.96± 0.14	5.0± 0.5	3.5± 0.35
7-S40-B	0.13±0.03	3.28± 0.23	1.47± 0.10	17.0± 1.7	12.0± 1.2
7-S40-C	0.19±0.05	2.86± 0.20	1.33± 0.09	15.0± 1.5	10.0± 1.0
7-S40-D	0.18±0.05	2.92± 0.20	1.48± 0.10	15.0± 1.5	10.0± 1.0

TABLE 4
(cont'd.)

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

	Ge(Li) Spectra, pCi/g±σ			Uranium Fluoromet	
Sample No.	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±σ	pCi/g±σ
SOIL BORINGS					
7-S56-1.0	0.21±0.01	3.14± 0.17	1.72± 0.09	11.8± 2.4	8.1± 1.6
7-S56-2.0	0.51±0.03	1.96± 0.12	1.31± 0.07	6.4± 1.3	4.4± 0.9
7-S56-3.0	0.01±0.01	1.17± 0.07	0.97± 0.05	14.8± 3.0	10.2± 2.1
7-S56-4.0	< 0.005	1.12± 0.07	0.90± 0.05	2.2± 0.4	1.5± 0.3
7-S56-5.0	< 0.005	0.99± 0.06	0.85± 0.05	2.0± 0.4	1.4± 0.3
7-S56-6.0	< 0.005	1.09± 0.07	0.86± 0.05	1.3± 0.3	0.9± 0.2
7-S56-7.0	< 0.005	1.19± 0.07	0.96± 0.05	1.6± 0.4	1.1± 0.3
7-S56-8.0	< 0.005	1.09± 0.07	0.82± 0.05	2.6± 0.5	1.8± 0.3
7-S56-9.0	< 0.005	0.99± 0.07	0.98± 0.06	2.3± 0.4	1.6± 0.3
7-S56-10.0	< 0.005	0.91± 0.06	0.69± 0.04	1.7± 0.3	1.2± 0.2
7-S57-1.0	0.19±0.01	5.09± 0.26	1.93± 0.10	38.8± 7.8	26.7± 5.4
7-S57-2.0	0.02±0.01	1.59± 0.09	1.03± 0.06	6.2± 1.2	4.3± 0.8
7-S57-3.0	< 0.005	1.39± 0.08	1.03± 0.06	3.8± 0.8	2.6± 0.5
7-S57-4.0	< 0.005	1.38± 0.09	0.99± 0.06	4.1± 0.8	2.8± 0.5
7-S57-7.0	0.04±0.01	1.88± 0.11	1.14± 0.06	10.7± 2.2	7.4± 1.5
7-S57-8.0	< 0.005	1.20± 0.07	0.97± 0.05	2.5± 0.5	4.1± 0.8
7-S57-9.0	< 0.005	1.24± 0.06	0.78± 0.03	5.9± 1.2	4.1± 0.8
7-S57-10.0	0.02±0.01	1.19± 0.07	1.05± 0.06	2.5± 0.5	1.7± 0.3
7-S58-1.0	0.03±0.01	1.41± 0.09	12.00± 0.66	37.1± 7.4	25.5± 5.1
7-S58-2.0	< 0.005	2.02± 0.11	2.48± 0.13	9.3± 1.8	6.4± 1.2
7-S58-3.0	< 0.005	1.90± 0.11	1.19± 0.06	5.4± 1.1	3.7± 0.8
7-S58-4.0	< 0.005	1.32± 0.08	3.80± 0.20	12.9± 2.6	8.9± 1.8
7-S58-5.0	< 0.005	1.47± 0.09	1.04± 0.06	3.7± 0.7	2.5± 0.5
7-S58-6.0	< 0.005	1.12± 0.07	0.91± 0.05	2.4± 0.5	1.6± 0.3
7-S58-7.0	< 0.005	1.17± 0.08	0.92± 0.05	1.9± 0.3	1.3± 0.2
7-S58-8.0	< 0.005	1.18± 0.07	0.99± 0.05	2.4± 0.5	1.6± 0.3
7-S58-9.0	< 0.005	1.10± 0.07	0.97± 0.06	2.1± 0.4	1.4± 0.3
7-S58-10.0	< 0.005	0.93± 0.06	0.85± 0.05	2.1± 0.4	1.4± 0.3

TABLE 4
(cont'd.)

Ge(Li) SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

Sample No.	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±σ	pCi/g±σ
SOIL BORINGS - (cont'd.)					
7-S59-1.0	0.17±0.01	0.95± 0.06	13.90± 0.70	48.1± 9.6	33.0± 6.6
7-S59-2.0	< 0.005	1.06± 0.07	3.45± 0.18	11.2± 2.2	7.7± 1.5
7-S59-3.0	< 0.005	1.07± 0.07	1.59± 0.09	3.8± 0.8	2.6± 0.5
7-S59-4.0	< 0.005	1.01± 0.07	2.78± 0.14	8.3± 1.6	5.7± 1.1
7-S59-5.0	< 0.005	1.01± 0.06	1.10± 0.06	2.4± 0.5	1.6± 0.3
7-S59-6.0	< 0.005	1.10± 0.07	1.60± 0.09	3.3± 0.7	2.3± 0.5
7-S59-7.0	< 0.005	0.94± 0.06	1.18± 0.06	2.8± 0.6	1.9± 0.4
7-S59-8.0	< 0.005	0.82± 0.06	2.15± 0.11	5.9± 1.2	4.1± 0.8
7-S59-9.0	< 0.005	0.69± 0.05	1.37± 0.07	3.0± 0.6	2.1± 0.4
7-S59-10.0	< 0.005	0.95± 0.06	1.08± 0.06	2.2± 0.4	1.5± 0.3
7-S60-1.0	0.16±0.01	2.89± 0.16	2.00± 0.11	7.3± 1.4	5.0± 1.0
7-S60-2.0	0.30±0.02	2.11± 0.12	1.35± 0.07	5.3± 1.1	3.6± 0.8
7-S60-3.0	< 0.005	1.10± 0.06	0.97± 0.05	2.2± 0.4	1.5± 0.3
7-S60-4.0	< 0.005	1.13± 0.07	0.94± 0.05	2.7± 0.5	1.9± 0.3
7-S60-5.0	< 0.005	1.05± 0.07	0.91± 0.05	1.9± 0.4	1.3± 0.3
7-S60-6.0	< 0.005	1.00± 0.07	0.89± 0.05	1.8± 0.4	1.2± 0.3
7-S60-7.0	< 0.005	1.10± 0.07	0.93± 0.05	1.7± 0.3	1.2± 0.2
7-S60-8.0	< 0.005	1.22± 0.07	0.92± 0.05	1.7± 0.3	1.2± 0.2
7-S60-9.0	< 0.005	1.08± 0.07	0.97± 0.06	2.2± 0.4	1.5± 0.3
7-S60-10.0	< 0.005	0.66± 0.05	0.74± 0.04	1.8± 0.4	1.2± 0.3
7-S61-1.0	0.67±0.04	2.24± 0.12	1.05± 0.06	6.7± 1.3	4.6± 0.9
7-S61-2.0	0.41±0.02	1.83± 0.11	1.34± 0.07	7.1± 1.4	4.9± 1.0
7-S61-3.0	0.06±0.01	1.16± 0.08	0.93± 0.05	3.4± 0.7	2.3± 0.5
7-S61-4.0	< 0.005	1.16± 0.08	1.06± 0.06	2.1± 0.4	1.4± 0.3
7-S61-5.0	< 0.005	1.15± 0.12	1.06± 0.08	2.1± 0.4	1.4± 0.3
7-S61-6.0	< 0.005	1.02± 0.06	0.95± 0.05	2.4± 0.5	1.6± 0.3
7-S61-7.0	< 0.005	1.13± 0.07	1.00± 0.06	2.0± 0.4	1.4± 0.3
7-S61-8.0	< 0.005	1.09± 0.07	0.98± 0.06	1.8± 0.4	1.2± 0.3
7-S61-9.0	< 0.005	0.91± 0.06	0.87± 0.05	2.0± 0.4	1.4± 0.3
7-S61-10.0	< 0.005	1.02± 0.07	0.94± 0.05	1.7± 0.3	1.2± 0.2

TABLE 4
(cont'd.)

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
Sample No.	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±σ	pCi/g±σ
SOIL BORINGS - (cont'd.)					
7-S62-1.0	0.33±0.07	0.98± 0.30	0.14± 0.02	25.0± 1.0	17.2± 0.7
7-S62-2.0	< 0.005	1.19± 0.20	4.20± 0.13	8.5± 0.4	5.8± 0.3
7-S62-3.0	< 0.005	1.10± 0.16	5.00± 0.10	14.0± 1.0	9.6± 0.7
7-S62-4.0	< 0.005	BDL[b]	3.60± 0.32	15.0± 1.0	10.3± 0.7
7-S62-5.0	< 0.005	1.09± 0.22	3.04± 0.13	10.0± 1.0	6.9± 0.7
7-S62-6.0	< 0.005	1.28± 0.16	1.65± 0.09	3.8± 0.3	2.6± 0.2
7-S62-7.0	< 0.005	1.13± 0.18	2.31± 0.11	9.0± 0.5	6.2± 0.3
7-S62-8.0	< 0.005	1.07± 0.17	0.85± 0.08	1.2± 0.2	0.8± 0.2
7-S62-9.0	< 0.005	0.86± 0.17	0.71± 0.09	2.2± 0.4	1.5± 0.3
7-S62-10.0	< 0.005	0.81± 0.15	0.68± 0.07	< 0.05	< 0.35
7-S63-1.0	0.59±0.08	5.70± 0.29	0.13± 0.01	50.0± 3.0	34.3± 2.1
7-S63-2.0	< 0.005	1.47± 0.52	6.34± 0.33	33.0± 2.0	22.7± 1.4
7-S63-5.0	< 0.005	1.10± 0.14	2.96± 0.08	21.0± 1.0	14.4± 0.7
7-S63-6.0	< 0.005	0.56± 0.33	1.29± 0.15	5.2± 0.3	3.6± 0.2
7-S63-7.0	< 0.005	0.93± 0.21	1.05± 0.10	1.6± 0.2	1.1± 0.2
7-S63-8.0	< 0.005	0.86± 0.14	0.73± 0.06	1.3± 0.2	0.9± 0.2
7-S63-9.0	< 0.005	0.67± 0.14	0.71± 0.07	0.7± 0.2	0.5± 0.2
7-S63-10.0	< 0.005	0.87± 0.11	0.62± 0.05	1.6± 0.3	1.1± 0.2
7-S64-1.0	0.28±0.07	4.36± 0.32	8.55± 0.19	7.5± 0.8	5.2± 0.5
7-S64-2.0	< 0.005	1.00± 0.16	1.05± 0.08	3.1± 0.4	2.1± 0.3
7-S64-3.0	< 0.005	1.35± 0.21	1.06± 0.12	2.0± 0.3	1.4± 0.2
7-S64-6.0	< 0.005	1.08± 0.23	0.84± 0.12	3.6± 0.4	2.5± 0.3
7-S64-7.0	< 0.005	0.90± 0.19	0.67± 0.09	2.0± 0.4	1.4± 0.3
7-S64-8.0	< 0.005	1.48± 0.16	0.77± 0.09	1.0± 0.2	0.7± 0.2
7-S64-9.0	< 0.005	1.12± 0.17	1.07± 0.09	2.4± 0.4	1.6± 0.3
7-S64-10.0	< 0.005	1.25± 0.15	0.76± 0.07	1.2± 0.3	0.8± 0.2
7-S65-1.0	< 0.005	1.27± 0.20	0.84± 0.09	3.3± 0.4	2.3± 0.3
7-S65-2.0	< 0.005	1.11± 0.15	0.85± 0.07	2.5± 0.3	1.7± 0.2
7-S65-3.0	< 0.005	0.82± 0.21	0.83± 0.11	1.5± 0.2	1.0± 0.2
7-S65-4.0	< 0.005	0.82± 0.18	0.79± 0.09	1.4± 0.2	1.0± 0.2
7-S65-5.0	< 0.005	1.22± 0.16	0.73± 0.07	3.0± 0.3	2.1± 0.2
7-S65-6.0	< 0.005	0.85± 0.31	1.22± 0.12	4.9± 0.2	3.4± 0.2
7-S65-7.0	< 0.005	1.02± 0.11	0.94± 0.05	1.2± 0.2	0.8± 0.2
7-S65-8.0	< 0.005	1.11± 0.17	0.67± 0.09	0.9± 0.2	0.6± 0.2
7-S65-9.0	< 0.005	0.94± 0.13	0.73± 0.06	1.9± 0.2	1.3± 0.2
7-S65-10.0	< 0.005	1.05± 0.09	0.68± 0.04	1.3± 0.3	0.9± 0.2

TABLE 4
(cont'd.)

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
Sample No.	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±σ	pCi/g±σ
SOIL BORINGS - (cont'd.)					
7-S66-1.0	< 0.005	BDL[b]	0.41± 0.33	12.0± 0.6	8.2± 0.4
7-S66-3.0	< 0.005	1.15± 0.17	0.56± 0.08	2.0± 0.4	1.4± 0.3
7-S66-4.0	< 0.005	0.93± 0.10	0.65± 0.04	< 0.5	< 0.35
7-S66-5.0	< 0.005	1.04± 0.14	0.69± 0.08	3.2± 0.5	2.2± 0.3
7-S66-6.0	< 0.005	0.98± 0.11	0.65± 0.05	0.9± 0.3	0.6± 0.2
7-S66-7.0	< 0.005	1.35± 0.20	0.37± 0.11	2.0± 0.3	1.4± 0.2
7-S66-8.0	< 0.005	1.00± 0.15	0.71± 0.07	1.5± 0.4	1.0± 0.3
7-S66-9.0	< 0.005	1.05± 0.13	0.69± 0.06	2.5± 0.4	1.7± 0.3
7-S66-10.0	< 0.005	1.28± 0.20	0.63± 0.11	2.4± 0.3	1.6± 0.2
7-S67-1.0	0.30±0.04	1.74± 0.15	0.60± 0.07	3.9± 0.4	2.7± 0.3
7-S67-2.0	< 0.005	5.25± 0.25	0.86± 0.09	18.0± 1.0	12.4± 0.7
7-S67-3.0	< 0.005	38.60± 0.60	2.25± 0.17	340.0±30	234.0±21
7-S67-4.0	< 0.005	2.47± 0.21	0.75± 0.11	7.7± 1.0	5.3± 0.7
7-S67-5.0	< 0.005	1.54± 0.14	0.78± 0.06	4.2± 0.3	2.9± 0.2
7-S67-6.0	< 0.005	1.52± 0.11	0.72± 0.06	3.8± 0.4	2.6± 0.3
7-S67-7.0	< 0.005	1.41± 0.19	0.72± 0.11	1.9± 0.3	1.3± 0.2
7-S67-8.0	< 0.005	0.87± 0.17	0.71± 0.08	2.2± 0.4	1.5± 0.3
7-S67-9.0	< 0.005	0.75± 0.13	0.52± 0.06	1.0± 0.2	0.7± 0.2
7-S67-10.0	< 0.005	1.06± 0.16	0.47± 0.10	1.6± 0.3	1.1± 0.2
7-S68-1.0	0.30±0.03	1.79± 0.13	1.12± 0.08	3.8± 0.4	2.6± 0.3
7-S68-2.0	< 0.03	0.89± 0.07	1.01± 0.07	2.5± 0.3	1.7± 0.2
7-S68-3.0	< 0.03	1.88± 0.13	0.23± 0.03	11.0± 1.1	7.6± 0.8
7-S68-4.0	< 0.03	1.67± 0.12	1.23± 0.09	6.4± 0.6	4.4± 0.4
7-S68-5.0	< 0.03	1.31± 0.09	1.23± 0.09	2.2± 0.2	1.5± 0.2
7-S68-6.0	< 0.03	1.01± 0.07	0.94± 0.07	2.0± 0.2	1.4± 0.2
7-S68-7.0	< 0.03	1.04± 0.07	1.38± 0.10	1.9± 0.2	1.3± 0.2
7-S68-8.0	0.12±0.03	0.99± 0.07	0.74± 0.07	2.8± 0.3	1.9± 0.2
7-S68-9.0	0.08±0.03	1.24± 0.09	0.65± 0.07	3.0± 0.3	2.1± 0.2
7-S68-10.0	< 0.03	0.67± 0.07	1.03± 0.07	1.7± 0.2	1.2± 0.2

TABLE 4
(cont'd.)

Ge(Li) SPECTRAL AND URANIUM FLUOROMETRIC ANALYSES OF SOIL SAMPLES

	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometri	
Sample No.	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±σ	pCi/g±σ
		SOIL BORINGS - (cont'd.)			
7-S69-1.0	0.09±0.04	0.20± 0.05	0.88± 0.07	1.8± 0.2	1.2± 0.2
7-S69-2.0	< 0.03	0.57± 0.06	0.76± 0.07	2.0± 0.2	1.4± 0.2
7-S69-3.0	< 0.03	0.53± 0.06	0.84± 0.07	10.5± 1.0	7.2± 0.7
7-S69-4.0	< 0.03	0.75± 0.07	0.70± 0.07	3.2± 0.3	2.2± 0.2
7-S69-5.0	< 0.03	0.68± 0.07	1.08± 0.08	2.2± 0.2	1.5± 0.2
7-S69-6.0	< 0.03	0.67± 0.07	1.23± 0.09	3.3± 0.3	2.3± 0.2
7-S69-7.0	0.06±0.03	0.71± 0.07	0.88± 0.07	2.1± 0.2	1.4± 0.2
7-S69-8.0	< 0.03	0.93± 0.07	1.26± 0.09	2.8± 0.3	1.9± 0.2
7-S69-9.0	< 0.03	0.96± 0.07	0.99± 0.07	2.0± 0.2	1.4± 0.2
7-S69-10.0	< 0.03	0.63± 0.07	0.72± 0.07	1.8± 0.2	1.2± 0.2
7-S70-1.0	0.17±0.04	1.80± 0.14	1.93± 0.14	5.1± 0.5	3.5± 0.3
7-S70-2.0	< 0.03	0.98± 0.07	1.16± 0.08	2.6± 0.3	1.8± 0.2
7-S70-3.0	< 0.03	0.83± 0.07	0.93± 0.07	2.3± 0.2	1.6± 0.2
7-S70-4.0	< 0.03	0.92± 0.07	1.10± 0.08	2.0± 0.2	1.4± 0.2
7-S70-5.0	< 0.03	0.57± 0.06	0.64± 0.07	1.7± 0.2	1.2± 0.2
7-S70-6.0	< 0.03	0.63± 0.07	0.69± 0.07	1.9± 0.2	1.3± 0.2
7-S70-7.0	< 0.03	0.53± 0.06	0.54± 0.06	1.6± 0.2	1.1± 0.2
7-S70-8.0	< 0.03	0.60± 0.06	0.90± 0.07	1.7± 0.2	1.2± 0.2
7-S70-9.0	< 0.03	0.50± 0.05	0.75± 0.07	1.5± 0.2	1.0± 0.2
7-S70-10.0	< 0.03	0.10± 0.05	0.41± 0.05	1.8± 0.2	1.2± 0.2
7-S71-1.0	0.06±0.03	1.03± 0.07	1.29± 0.09	1.8± 0.2	1.2± 0.2
7-S71-2.0	0.05±0.03	1.00± 0.07	1.14± 0.08	1.9± 0.2	1.3± 0.2
7-S71-3.0	< 0.03	0.86± 0.08	0.82± 0.07	1.8± 0.2	1.2± 0.2
7-S71-4.0	< 0.03	0.94± 9.07	1.27± 0.09	1.4± 0.2	1.0± 0.2
7-S71-5.0	< 0.03	1.07± 0.07	0.96± 0.07	1.4± 0.2	1.0± 0.2
7-S71-6.0	< 0.03	1.04± 0.07	0.69± 0.07	1.4± 0.2	1.0± 0.2
7-S71-7.0	< 0.03	1.02± 0.07	1.12± 0.08	1.5± 0.2	1.0± 0.2
7-S71-8.0	< 0.03	0.80± 0.07	1.02± 0.07	1.4± 0.2	1.0± 0.2
7-S71-9.0	< 0.03	0.59± 9.07	0.78± 0.07	1.3± 0.2	0.9± 0.2
7-S71-10.0	< 0.03	0.53± 0.05	0.41± 0.04	1.4± 0.2	1.0± 0.2
7-S72-1.0	0.18±0.04	2.90± 0.20	2.61± 0.18	9.9± 1.0	6.8± 0.7
7-S72-2.0	0.33±0.03	1.73± 0.12	2.18± 0.15	4.9± 0.5	3.4± 0.3
7-S72-3.0	< 0.03	1.39± 0.10	0.98± 0.07	2.2± 0.2	1.5± 0.2
7-S72-4.0	< 0.03	1.19± 0.08	1.47± 0.10	2.0± 0.2	1.4± 0.2
7-S72-6.0	< 0.03	1.35± 0.09	1.34± 0.09	1.9± 0.2	1.3± 0.2
7-S72-7.0	< 0.03	1.32± 0.09	1.24± 0.08	1.9± 0.2	1.3± 0.2
7-S72-8.0	< 0.03	0.76± 0.07	0.56± 0.06	1.8± 0.2	1.2± 0.2
7-S72-9.0	< 0.03	1.00± 0.07	1.11± 0.08	1.7± 0.2	1.2± 0.2
7-S72-10.0	< 0.03	0.88± 0.08	0.59± 0.06	1.5± 0.2	1.0± 0.2

TABLE 4
(cont'd.)

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

Sample No.	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±σ	pCi/g±σ
	SOIL BORINGS - (cont'd.)				
7-S73-1.0	0.08±0.03	10.50± 0.7	2.80± 0.20	9.1± 0.9	6.3± 0.4
7-S73-2.0	0.78±0.06	57.70± 4.0	33.20± 2.3	50.1± 5.0	34.4± 3.4
7-S73-3.0	0.15±0.04	1.28± 0.09	1.35± 0.09	2.9± 0.3	2.0± 0.2
7-S73-4.0	0.14±0.03	3.41± 0.24	1.87± 0.13	4.6± 0.5	3.2± 0.3
7-S73-5.0	< 0.03	1.40± 0.10	0.99± 0.07	2.4± 0.2	1.6± 0.2
7-S73-6.0	< 0.03	1.27± 0.09	1.12± 0.08	2.4± 0.2	1.6± 0.2
7-S73-7.0	< 0.03	1.15± 0.08	1.24± 0.09	2.4± 0.2	1.6± 0.2
7-S73-8.0	< 0.03	0.69± 0.06	0.67± 0.06	2.1± 0.2	1.4± 0.2
7-S73-9.0	< 0.03	0.82± 0.07	0.73± 0.07	2.1± 0.2	1.4± 0.2
7-S73-10.0	< 0.03	0.69± 0.06	1.02± 0.07	2.0± 0.2	1.4± 0.2
7-S74-1.0	0.30±0.04	4.10± 0.29	6.38± 0.45	17.1± 1.7	11.7± 1.2
7-S74-2.0	0.51±0.07	1.47± 0.16	4.21± 0.29	18.0± 1.8	12.4± 1.2
7-S74-5.0	0.11±0.03	0.83± 0.07	0.94± 0.07	3.2± 0.3	2.2± 0.2
7-S74-6.0	0.04±0.02	0.53± 0.07	0.90± 0.07	2.4± 0.2	1.6± 0.2
7-S74-7.0	< 0.03	1.25± 0.09	1.41± 0.10	2.9± 0.3	2.0± 0.2
7-S74-8.0	< 0.03	1.46± 0.10	1.41± 0.10	2.2± 0.2	1.5± 0.2
7-S74-9.0	< 0.03	0.92± 0.07	1.29± 0.09	3.0± 0.3	2.1± 0.2
7-S74-10.0	< 0.03	0.50± 0.07	0.79± 0.07	2.4± 0.2	1.6± 0.2
7-S75-1.0	0.14±0.05	2.65± 0.19	1.28± 0.09	3.7± 0.4	2.5± 0.3
7-S75-2.0	0.05±0.03	1.18± 0.08	0.94± 0.07	2.8± 0.3	1.9± 0.2
7-S75-3.0	< 0.03	1.28± 0.09	1.33± 0.09	2.6± 0.3	1.8± 0.2
7-S75-4.0	c	c	c	2.2± 0.2	1.5± 0.2
7-S75-5.0	< 0.03	1.06± 0.07	1.27± 0.09	2.2± 0.2	1.5± 0.2
7-S75-6.0	< 0.03	1.17± 0.08	0.97± 0.07	2.1± 0.2	1.4± 0.2
7-S75-7.0	< 0.03	1.29± 0.09	1.57± 0.11	1.9± 0.2	1.3± 0.2
7-S75-8.0	< 0.03	1.45± 0.10	1.35± 0.09	1.9± 0.2	1.3± 0.2
7-S75-9.0	< 0.03	0.71± 0.07	1.54± 0.11	2.3± 0.2	1.6± 0.2
7-S75-10.0	< 0.03	1.15± 0.08	1.18± 0.08	2.1± 0.2	1.4± 0.2

TABLE 4
(cont'd.)

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

Sample No.	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±σ	pCi/g±σ
		SOIL BORINGS - (cont'd.)			
7-S76-1.0	0.17±0.05	1.20± 0.08	1.48± 0.10	3.3± 0.3	2.3± 0.2
7-S76-2.0	< 0.03	1.19± 0.08	1.44± 0.10	2.4± 0.2	1.6± 0.2
7-S76-3.0	< 0.03	1.03± 0.07	1.32± 0.09	2.0± 0.2	1.4± 0.2
7-S76-4.0	< 0.03	1.13± 0.08	1.06± 0.07	1.9± 0.2	1.3± 0.2
7-S76-5.0	< 0.03	1.27± 0.09	1.19± 0.08	2.0± 0.2	1.4± 0.2
7-S76-6.0	< 0.03	0.95± 0.07	1.36± 0.10	1.8± 0.2	1.2± 0.2
7-S76-7.0	< 0.03	1.39± 0.10	1.30± 0.09	2.1± 0.2	1.4± 0.2
7-S76-8.0	< 0.03	1.24± 0.09	1.50± 0.10	2.1± 0.2	1.4± 0.2
7-S76-9.0	< 0.03	0.84± 0.07	1.19± 0.08	2.1± 0.2	1.4± 0.2
7-S77-1.0	0.18±0.04	1.16± 0.08	1.16± 0.08	2.2± 0.2	1.5± 0.2
7-S77-2.0	0.03±0.02	1.28± 0.09	0.98± 0.07	2.2± 0.2	1.5± 0.2
7-S77-3.0	0.06±0.03	1.18± 0.08	0.88± 0.07	1.9± 0.2	1.3± 0.2
7-S77-4.0	< 0.03	1.17± 0.08	1.25± 0.09	1.8± 0.2	1.2± 0.2
7-S77-5.0	0.04±0.02	0.98± 0.07	0.87± 0.07	1.8± 0.2	1.2± 0.2
7-S77-6.0	< 0.03	1.30± 0.09	1.26± 0.09	1.8± 0.2	1.2± 0.2
7-S77-7.0	0.04±0.02	0.79± 0.07	0.87± 0.07	1.9± 0.2	1.3± 0.2
7-S77-8.0	< 0.03	1.08± 0.08	0.90± 0.07	2.0± 0.2	1.4± 0.2
7-S77-9.0	0.04±0.02	0.64± 0.07	0.70± 0.07	2.1± 0.2	1.4± 0.2
7-S77-10.0	0.07±0.03	0.85± 0.07	0.97± 0.07	2.6± 0.2	1.8± 0.2
7-S78-1.0	0.31±0.04	1.49± 0.10	1.38± 0.10	2.1± 0.2	1.4± 0.2
7-S78-2.0	< 0.03	1.66± 0.12	1.50± 0.10	2.4± 0.2	1.6± 0.2
7-S78-3.0	< 0.03	1.10± 0.08	1.59± 0.11	2.2± 0.2	1.5± 0.2
7-S78-4.0	< 0.03	0.98± 0.07	0.84± 0.07	1.8± 0.2	1.2± 0.2
7-S78-5.0	< 0.03	1.46± 0.10	1.48± 0.10	1.8± 0.2	1.2± 0.2
7-S78-6.0	< 0.03	1.05± 0.07	1.14± 0.08	1.8± 0.2	1.2± 0.2
7-S78-7.0	< 0.03	0.97± 0.07	0.99± 0.07	1.9± 0.2	1.3± 0.2
7-S78-8.0	< 0.03	1.10± 0.08	1.08± 0.08	1.8± 0.2	1.2± 0.2
7-S78-9.0	< 0.03	0.87± 0.07	0.99± 0.07	1.7± 0.2	1.2± 0.2
7-S78-10.0	< 0.03	0.87± 0.07	1.07± 0.07	1.8± 0.2	1.2± 0.2

TABLE 4
(cont'd.)

Ge(Li)-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

Sample No.	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±σ	pCi/g±σ
		SOIL BORINGS - (cont'd.)			
7-S79-1.0	0.18±0.04	1.15± 0.08	0.84± 0.07	2.1± 0.2	1.4± 0.2
7-S79-2.0	< 0.03	1.18± 0.08	1.46± 0.10	2.1± 0.2	1.4± 0.2
7-S79-3.0	< 0.03	1.09± 0.08	1.37± 0.10	1.8± 0.2	1.2± 0.2
7-S79-4.0	< 0.03	0.76± 0.07	0.75± 0.07	1.7± 0.2	1.2± 0.2
7-S79-5.0	< 0.03	0.88± 0.07	0.86± 0.07	1.8± 0.2	1.2± 0.2
7-S79-6.0	< 0.03	1.30± 0.09	1.42± 0.10	1.9± 0.2	1.3± 0.2
7-S79-7.0	< 0.03	1.06± 0.07	1.30± 0.09	1.9± 0.2	1.3± 0.2
7-S79-8.0	< 0.03	1.11± 0.08	1.31± 0.09	1.9± 0.2	1.3± 0.2
7-S79-9.0	< 0.03	0.58± 0.07	0.92± 0.07	1.7± 0.2	1.2± 0.2
7-S79-10.0	< 0.03	0.86± 0.07	0.72± 0.07	1.6± 0.2	1.1± 0.2
7-S80-1.0	0.18±0.04	1.35± 0.09	1.45± 0.10	1.9± 0.2	1.3± 0.2
7-S80-2.0	< 0.03	0.89± 0.07	1.17± 0.08	2.2± 0.2	1.5± 0.2
7-S80-3.0	< 0.03	0.87± 0.07	0.93± 0.07	1.9± 0.2	1.3± 0.2
7-S80-4.0	< 0.03	0.96± 0.07	1.27± 0.09	1.6± 0.2	1.1± 0.2
7-S80-5.0	< 0.03	1.15± 0.08	1.30± 0.09	1.9± 0.2	1.3± 0.2
7-S80-6.0	0.05±0.02	1.04± 0.07	0.94± 0.07	2.0± 0.2	1.4± 0.2
7-S80-7.0	< 0.03	1.56± 0.11	1.57± 0.11	1.9± 0.2	1.3± 0.2
7-S80-8.0	< 0.03	1.27± 0.09	1.31± 0.09	1.9± 0.2	1.3± 0.2
7-S80-9.0	< 0.03	0.67± 0.07	0.75± 0.07	1.8± 0.2	1.2± 0.2
7-S80-10.0	< 0.03	0.86± 0.07	0.92± 0.07	1.9± 0.2	1.3± 0.2
7-S81-1.0	0.12±0.03	1.75± 0.12	1.59± 0.11	3.7± 0.4	2.5± 0.3
7-S81-2.0	0.09±0.04	0.99± 0.07	0.98± 0.07	8.9± 0.9	6.1± 0.6
7-S81-3.0	< 0.03	1.04± 0.07	1.07± 0.08	3.6± 0.4	2.5± 0.3
7-S81-4.0	< 0.03	1.14± 0.08	1.09± 0.08	2.4± 0.3	1.6± 0.2
7-S81-5.0	< 0.03	1.17± 0.08	1.26± 0.09	2.5± 0.3	1.7± 0.2
7-S81-6.0	< 0.03	1.27± 0.09	1.16± 0.08	2.3± 0.2	1.6± 0.2
7-S81-7.0	< 0.03	1.52± 0.11	1.53± 0.11	2.2± 0.2	1.5± 0.2
7-S81-8.0	< 0.03	1.15± 0.08	1.28± 0.09	2.1± 0.2	1.4± 0.2
7-S81-9.0	< 0.03	1.15± 0.08	1.11± 0.08	2.1± 0.2	1.4± 0.2
7-S81-10.0	< 0.03	1.44± 0.10	1.38± 0.10	2.2± 0.2	1.5± 0.2

TABLE 4
(cont'd.)

Ge(Li) SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

Sample No.	Ge(Li) Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±σ	pCi/g±σ
		AUXILLIARY SUBSURFACE SAMPLES			
7-S89-3.0	< 0.03	0.83± 0.08	0.91± 0.09	1.6± 0.2	1.1± 0.2
7-S90-3.0	< 0.03	0.71± 0.07	0.82± 0.08	1.6± 0.2	1.1± 0.2
7-S91-3.0	0.06±0.03	0.98± 0.10	0.86± 0.09	1.8± 0.2	1.2± 0.2
7-S92-1.0	< 0.03	1.37± 0.14	86.0 ± 9.0	286.0±30	196.0±21
7-S94	BDL[b]	0.79± 0.08	0.57± 0.06		
7-S95	< 0.03	0.63± 0.09	0.73± 0.07		
7-S96	BDL[b]	0.84± 0.08	0.71± 0.07		
7-S97	< 0.03	1.07± 0.11	0.75± 0.08		
7-S98	< 0.03	0.96± 0.10	0.81± 0.08		

[a] The letter identifications A, B, C, and D refer to the 2-inch, 2-inch, 2-inch, and 6-inch segments respectively of the 1-ft soil corings.

[b] BDL - Below Detectable Levels

[c] Insufficient sample

TABLE 5

GAMMA SPECTRAL AND URANIUM FLUOROMETRIC ANALYSES OF WATER SAMPLES

(See Figure 3)

	Ge(Li) Spectra, pCi/g±σ			
Sample No.	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	^{110m}Ag
7-W88	BDL[a]	0.017±0.001	0.02±0.001	-
		Dissolved Solids pCi/mℓ ±1σ		
7-W132	< 0.03	< 0.06	BDL[a]	BDL
7-W133	< 0.03	< 0.06	< 0.02	BDL
7-W134	< 0.03	< 0.06	< 0.02	BDL
7-W135	0.04±0.02	< 0.06	< 0.02	BDL
7-W136	< 0.03	< 0.06	< 0.02	BDL
7-SS137	0.09±0.03	< 0.06	0.03±0.01	BDL
7-SS138	0.06±0.02	< 0.06	< 0.02	BDL
7-SS139	0.12±0.04	< 0.06	0.26±0.03	BDL
7-SS140	0.04±0.02	< 0.06	0.33±0.03	BDL
		Suspended Solids pCi/g ± 1σ		
7-W132	< 0.03	BDL	0.05±0.02	12±5
7-W133	2.10±0.21	< 0.06	< 0.02	BDL
7-W134	BDL	BDL	12.0 ±1.2	BDL
7-W135	< 0.03	< 0.06	< 0.02	BDL
7-W136	3.60±0.36	< 0.06	< 0.02	BDL
7-SS137	0.08±0.02	< 0.06	< 0.02	BDL
7-SS138	0.20±0.03	< 0.06	< 0.02	BDL
7-SS139	0.14±0.03	0.56±0.09	0.10±0.03	BDL
7-SS140	0.24±0.02	< 0.06	< 0.02	BDL

URANIUM FLUOROMETRIC

Sample No.	g Total Solids	µg Total U in Solids	pCi Total U in Solids	mℓ Total Solution	µg Total U in Solution	pCi Total U in Solution
7-W88	b	b	b	128.0	8.8	6.1
7-W132	26.9	78	53.6	968.5	< 1	< 0.7
7-W133	0.027	0.050	0.034	282.7	< 0.1	< 0.07
7-W134	0.020	0.030	0.020	283.2	< 0.1	< 0.07
7-W135	1.49	0.95	0.65	265.3	< 0.1	< 0.07
7-W136	0.27	0.21	0.14	285.5	< 0.1	< 0.07

Table 5
(cont'd.)

URANIUM FLUOROMETRIC						
Sample No.	g Total Solids	g Total U in Solids	pCi Total U in Solids	mℓ Total Solution	μg Total U in Solution	pCi Total U in Solution
7-SS137	33.4	17.4	11.9	91.9	< 0.1	< 0.07
7-SS138	24.5	13.2	9.0	97.8	< 0.1	< 0.07
7-SS139	33.1	26.4	18.0	84.6	< 0.1	< 0.07
7-SS140	30.9	10.4	7.1	108.7	< 0.1	< 0.07

[a] BDL - Below Detectable Levels

[b] Not Determined

TABLE 6

THORIUM ISOTOPIC ANALYSIS

Sample No.	pCi/g±σ ^{232}Th	 ^{228}Th	 ^{230}Th
7-S28-C	90± 9	99± 9	30± 5
7-S39-D	1570±140	1410±130	160± 4
7-S67-3	39± 4	44± 5	28± 3
7-S73-2	27± 5	28± 5	200±20

TABLE 7

SOIL SAMPLE LOCATIONS

Hole Number	X Coordinate	Y Coordinate
BIOMASS FACILITY (Fig. 7)		
7-S39	12.40	N.05
7-S40	0.60	H.92
7-S65	7.00	A.05
7-S66	5.50	B.00
7-S67	7.80	C.20
7-S68	9.20	C.35
7-S69	10.75	B.95
7-S70	11.85	I.20
7-S71	12.35	F.40
7-S72	0.30	H.80
7-S89	11.30	L.45
7-S90	11.30	M.00
7-S91	11.35	Q.40
7-S92	11.35	Q.40
7-S94	11.30	K.90
7-S95	11.25	I.45
7-S96	11.05	G.30
7-S97	11.20	D.70
7-S98	11.20	B.20
7-W132	9.40	C.45
BACK FORTY (Fig. 8)		
7-S26	2.62	H.88
7-S27	10.71	J.02
7-S28	10.32	J.35
7-S29	10.71	K.12
7-S30	9.72	J.72

TABLE 7

(cont'd.)

SOIL SAMPLE LOCATIONS

Hole Number	X Coordinate	Y Coordinate
7-S31	8.46	F.50
7-S32	8.45	K.45
7-S56	10.80	L.05
7-S57	10.80	K.02
7-S58	10.80	I.95
7-S59	9.59	K.59
7-S60	10.30	K.40
7-S61	9.45	K.92
7-S62	9.62	J.75
7-S63	10.15	J.60
7-S64	10.45	J.30
7-S73	9.00	K.92
7-S74	9.10	K.20
7-S75	9.15	J.50
7-S76	8.60	K.00
7-S77	10.80	G.52
7-S78	6.70	G.30
7-S79	6.65	J.80
7-S80	6.65	I.56
7-S81	8.96	L.27
7-S88	9.00	K.92

TABLE 8

ESTIMATED VOLUME, MASS AND ACTIVITY OF MATERIAL THAT COULD BE GENERATED BY REMEDIAL ACTION

Area and Material Involved	Estimated Volume		Estimated Mass		Estimated Activity (Curies)[b]			
	m^3	ft^3	kg	lbs. (avoir)	^{226}Ra Chain	Natural Thorium	Natural Uranium	Normal Uranium
Option #1 Soil under BioMass area (ρ=1.5 g/cm^3)	9.86×10^3	3.48×10^5	1.48×10^7	3.26×10^7	0.13	2.53	0.50	0.15
Option #2 Soil under BioMass area (ρ=1.5 g/cm^3)	1.48×10^4	5.23×10^5	2.22×10^7	4.89×10^7	0.35	41.0[c]	2.17	2.08
Option #1 Soil in Back Forty area (ρ=1.5 g/cm^3)	3.55×10^3	1.25×10^5	5.33×10^6	1.17×10^7	0.004	0.11	0.067	0.03
Option #2 Soil in Back Forty area (ρ=1.5 g/cm^3)	8.88×10^3	3.14×10^5	1.33×10^7	2.93×10^7	0.011	1.61	0.69	0.22

[a] See text (pages 11 & 12) for assumptions upon which estimates are based.

[b] A Curie is 3.7×10^{10} disintegrations per second.

[c] The calculated 41 Curies of natural thorium (maximum condition) computes to approximately 203 tons of thorium; this is obviously an overestimation.

APPENDIX 1

INSTRUMENTATION

I. PORTABLE RADIATION SURVEY METERS

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 was the primary instrument used for surveying. This instrument is a gas-flow proportional counter which utilizes a propane gas-proportional detector, 51 cm^2 (PAC-4G-3) or 325 cm^2 (FM-4G) in area, with a thin double-aluminized Mylar window ($\sim$ 0.85 mg/cm^2).

Since this instrument has multiple high-voltage positions, it can be used to distinguish between alpha and beta-gamma contamination. This instrument was initially used in the beta mode. In the beta mode, the detector responds to alpha and beta paticles and x- and gamma-rays. When areas indicated a higher count rate than the average instrument background, the beta-mode reading was recorded, and the instrument was then switched to the alpha mode to determine any alpha contribution. In the alpha mode, the instrument responds only to particles with high-specific ionization. This instrument is calibrated in the alpha mode with a flat-plate infinitely-thin NBS traceable ^{239}Pu standard, and in the beta mode with a flat-plate infinitely-thin NBS traceable ^{90}Sr-^{90}Y standard. The PAC-4G-3 instruments are calibrated to an apparent 50% detection efficiency.

B. Beta-Gamma End Window Survey Meter

When an area of contamination was found with a PAC instrument, a reading was taken with an Eberline Beta-gamma Geiger-Mueller Counter, Model E-530 with a HP-190 probe. This probe has a thin mica end window and is, therefore, sensitive to alpha and beta particles and x- and gamma-rays. A thin piece of aluminum is added to the mica, making the window density approximately 7 mg/cm^2. At this density, the instrument is not sensitive to the majority of alpha emissions. A maximum reading is obtained with the probe placed in contact with the area of contamination. Another reading is obtained with the probe held 1 m from the contaminated area. This instrument is calibrated with an NBS traceable ^{137}Cs source.

C. Low Energy Gamma Scintillation Survey Meter

An Eberline Model PRM-5-3 with a PG-2 gamma scintillation detector was used to determine low energy x and gamma radiation. The PG-2 detector consists of a thin NaI(Tℓ) scintillation crystal 5 cm in diameter by 2 mm thick. This instrument is calibrated on three separate discriminators for three energy regions using ^{239}Pu (17 keV), ^{241}Am (59.5 keV) and ^{235}U (185.7 keV) sources. This instrument can be operated in either a differential (to discriminate between different energy regions) or integral mode.

APPENDIX 1
(cont'd.)

D. High Energy Micro "R" Scintillation Survey Meter

An Eberline Micro "R" meter model PRM-7 was used to detect high-energy gamma radiation. This instrument contains an internally mounted NaI(Tℓ) scintillation crystal 2.5 cm in diameter by 2.5 cm thick and can be used for measuring fields of low-level radiation between 10 μR/h and 5000 μR/h. This instrument is also calibrated with an NBS traceable ^{226}Ra source.

E. Integrating Radiation Meter

In addition to the PRM-7, a pressurized ion chamber (Reuter Stokes Model RSS-111) was used at selected locations to determine the ambient radiation field. The RSS-111 has three output modes; (1) instantaneous exposure rate, (2) strip chart differential readout, and (3) integrated exposure. This instrument is mounted on a tripod, 3 ft (~ 1 m) above the surface and has a uniform energy response from about 0.2 MeV to about 4 MeV. A 3-h period of operation is usually sufficient to obtain significant data.

II. SMEAR COUNTING INSTRUMENTATION

An ANL-designed gas-flow proportional detector connected to an Eberline Mini Scaler Model MS-2 was used to count multiple smears simultaneously. This detector has a double-aluminized Mylar window (400 cm^2) and uses P-10 (90% argon and 10% methane) as the counting gas. The metal sample holder for this detector has been machined to hold ten smear papers. This particular system consists of two Mini Scalers and two detectors. One is used for counting in the alpha mode; the other is used in the beta mode. Up to ten samples can be counted simultaneously.

Any smear taken from a contaminated area was counted individually in a Nuclear Measurements Corporation PC-5 gas-flow proportional counter. This instrument has been modified to contain a double-aluminized Mylar spun top. This top is placed over non-conducting media (e.g. paper smears) to negate the dielectric effect on the counter. This counter also uses P-10 counting gas. Smears are counted in both the alpha and beta modes. This instrument is calibrated by determining the input sensitivity using an alpha source.

III. AIR SAMPLING DEVICE

Air samples were collected using a commercially available (ANL-modified filter queen) vacuum cleaner identified as a "Princess Model." The air was drawn through a filter media at a flow rate of 40 m^3/h. The filter media consist of 200 cm^2 sheets of Hollingsworth-Vose (HV-70 or LB5211-9 mil) filter paper. The collection efficiency at these flow rates for 0.3-micron particles is about 99.9%.

A separate air sample can be taken with a positive displacement pump drawing about 20 liters/min through a millipore (0.5 to 0.8 micron) filter paper for about one hour. An alpha spectrum can be measured from a section of this filter paper. The ratio of actinon (^{219}Rn - 6.62 MeV α AcC) to radon (^{222}Rn - 7.69 MeV RaC') can be determined from this spectrum.

IV. GAMMA SPECTRAL INSTRUMENTATION

A Nuclear Data Multichannel Analyzer Model ND-100, utilizing a 7.6-cm-diameter by 7.6-cm-thick NaI(Tℓ) scintillation crystal is commonly used for determining gamma spectrum. This instrument is calibrated with NBS traceable gamma sources. Samples from contaminated areas were analyzed using this sytem and the contamination radionuclides were identified.

Hyperpure Germanium detectors (ORTEC - 17% efficiency right-circular cylinders) were used when more sophisticated gamma-ray analyses were required. These detectors are coupled to Nuclear Data Multichannel Analyzers (Models ND-60, ND-66 or ND-100).

APPENDIX 2

CONVERSION FACTORS

I. INSTRUMENTATION

The factors used to convert the instrument readings to units of disintegrations per minute per 100 cm^2 (dis/min-100 cm^2) and the derivation of those factors are listed below.

A. Conversion Factors

	PAC-4G-3		Floor Monitor (FM-4G)	
	Alpha	Beta	Alpha	Beta
To 100 cm^2	1.96	1.96	0.31	0.31
cts/min to dis/min for ^{90}Sr-^{90}Y	-	2	-	2
cts/min to dis/min for ^{239}Pu	2	-	2	-
cts/min to dis/min for normal U	5.9	3.5	5.9	3.5
cts/min to dis/min ^{226}Ra plus daughters	1.6	4.7	-	-

B. Derivation of Conversion Factors

. Floor Monitor

Window Area: ~ 325 cm^2
Conversion to 100 cm^2 = 0.31 times Floor Monitor readings

. PAC-4G-3

Window Area: ~ 51 cm^2
Conversion to 100 cm^2 = 1.96 times PAC reading

. 2π Internal Gas-Flow Counter, PC counter

Geometry: Solid Steel Spun Top - 0.50

Geometry: Mylar Spun Top - 0.43
Mylar spun top counting {double-aluminized Mylar window (~ 0.85 mg/cm^2)} utilizes the well of the PC counter and is a method developed and used by the Argonne National Laboratory Health Physics Section for negating the dielectric effect in counting samples on nonconducting media.

APPENDIX 2
(cont'd.)

Using a flat-plate, infinitely thin ^{226}Ra plus short-lived daughters standard as a source of alpha emissions, the plate was counted in the well of a 2π Internal Gas-Flow Counter (PC counter) with the source leveled to an apparent 2π geometry. This instrument was calibrated using ^{239}Pu NBS traceable alpha sources. The alpha counts per minute (cts/min) reading was found to be 1.8×10^4 cts/min, or $1.8 \times 10^4 \div 0.51^* = 3.5 \times 10^4$ disintegrations per minute (dis/min) alpha. Since the source was infinitely-thin, the alpha component was used as the total alpha dis/min of the source.

The same ^{226}Ra plus daughters source, when counted with the PAC instrument in the alpha mode, was found to be 2.2×10^4 cts/min at contact. The conversion factor for cts/min to dis/min for the PAC instrument is $3.5 \times 10^4 \div 2.2 \times 10^4 = 1.6$ dis/min alpha to cts/min alpha.

The same source was covered with two layers of conducting paper, each 6.65 mg/cm^2, to absorb the alpha emissions. With the PAC-4G-3 in the beta mode and in contact with the covered source in the center of the probe, the count was found to be 7.5×10^3 cts/min. This indicates a conversion factor of $3.5 \times 10^4 \div 7.5 \times 10^3 = 4.7$ dis/min alpha to cts/min beta-gamma.

A similar method was used to determine the conversion factors for normal uranium.

II. SMEAR COUNT

The conversion factors for cts/min-100 cm^2 to dis/min-100 cm^2 for smear counts are given below:

A. Conversion Equation (Alpha)

$$\frac{\text{cts/min - (Bkgd)}}{\text{g x bf x sa x waf}} = \text{dis/min } \alpha$$

A geometry (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.0 was used when determining alpha activity on a filter media.

The self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

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*The value of 0.51 includes the following factors: geometry (g) = 0.50; backscatter factor (bf) = 1.02; sample absorption factor (sa) = 1.0; window air factor (waf) = 1.0. The product of g x bf x sa x waf is 0.51.

APPENDIX 2
(Cont'd.)

If the energies of the isotope were known, the appropriate window air factor (waf) was used; if the energies of the isotopes were not known, the (waf) of ^{239}Pu (0.713) was used.

The (waf) for alpha from ^{226}Ra plus daughters is 0.55.

B. Conversion Equation (Beta)

$$\frac{\text{cts/min} - \{\beta \text{ Bkgd (cts/min)} + \alpha \text{ cts/min}\}}{\text{g x bf x sa x waf}} = \text{dis/min } \beta$$

A geometry (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.1 was used when determining beta activity on a filter media.

A self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

If the energies of the isotopes were known, the appropriate window air factor (waf) was used; if the energies of the isotopes were unknown, the (waf) of ^{90}Sr-^{90}Y (0.85) was used.

The (waf) for betas from ^{226}Ra plus daughters is 0.85.

APPENDIX 3

RADON-DETERMINATION CALCULATIONS

Calculations for air samples collected with an Argonne National Laboratory-designed air sampler using HV-70 or LB5211 filter media are summarized in this appendix. The appendix also includes the basic assumptions and calculations used to derive the air concentrations.

I. RADON CONCENTRATIONS

The following postulates are assumed in deriving the radon (^{222}Rn) concentrations based on the RaC' alpha count results.

A. RaA, RaB, RaC, and RaC' are in equilibrium.

B. RaA is present only in the first count and not the 100-minute decay count.

C. One-half of the radon progeny is not adhered to airborne particulates (i.e., unattached fraction) and, therefore, is not collected on the filter media.

D. The geometry factor (g) is 0.43 for both the alpha and beta activity.

E. The backscatter factor (bf) of 1.0 is used for the alpha activity.

F. The sample absorption factor (sa) for RaC' is 0.77.

G. The window air factor (waf) for RaC' is 0.8.

H. RaB and RaC, being beta emitters, are not counted in the alpha mode.

I. The half-life of the radon progeny is approximately 36 minutes, based on the combined RaB and RaC half-lives.

J. Thoron and long-lived alpha emitters are accounted for using the 360 count and the seven-day count, respectively.

K. For all practical purposes, RaC' decays at the rate of the composite of RaB and RaC, which is about 36 minutes.

The following postulates are assumed in deriving the thoron (^{220}Rn) concentrations.

L. ThA, ThB, ThC and ThC' are in equilibrium.

M. ThA and RaC' have decayed by the 360 minute decay count.

APPENDIX 3
(cont'd.)

N. The geometry factor (g), backscatter factor (bf), sample absorption factor (sa) and window air factor (waf) are all the same for thoron as for radon.

O. ThB and 64% of ThC, being beta emitters, are not counted in the alpha mode.

P. The half-life of the thoron progeny is 10.64 hours (638.4 minute) based on the ThB half-life.

Q. For all practical purposes 36% of the ThC (alpha branch) and the ThC' decay at the decay rate of ThB which is 638.4 minute.

R. The counter does not differentiate between the ThC alphas and the ThC' alphas.

The following postulates are assumed in deriving the actinon (^{219}Rn) concentrations.

S. AcA, AcB and AcC are in equilibrium.

T. AcA has decayed by the 100 minute decay count.

U. The geometry (g), backscatter (bf), sample absorption (sa) and window air factor (waf) factors are all the same for actinon as for radon.

V. AcB, being a beta emitter, is not counted in the alpha mode.

W. The half-life of the actinon progeny is 36.1 minutes based on the AcB half-life.

X. For all practical purposes, the AcC decays at the decay rate of AcB which is 36.1 minutes.

Y. 84% of the AcC decays by 6.62 MeV α emissions and 16% decays by 6.28 MeV α emissions.

The following postulate is assumed in deriving the long-lived concentration. The long-lived activity, as determined from the seven-day count, is assumed to be constant during the entire counting periods. This assumption is valid for isotopes with half-lives longer than a few years.

II. EQUATIONS USED TO DERIVE AIR CONCENTRATIONS

$$A_o = \frac{A}{e^{-\lambda t}}$$

Where: A_o = Activity (dis/min) present at the end of the sampling period (usually 40 minutes)

APPENDIX 3
(cont'd.)

A = Activity (dis/min) at some time, t, after end of the sampling period

t = Time interval (minute) from end of sampling period to counting interval (usually $\simeq$ 100 minutes)

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

$t_{\frac{1}{2}}$ = Half-life of isotope (min)

Concentration is determined by the equation:

$$C = \frac{A_o \lambda}{f} \times \frac{1}{1-e^{-\lambda t_s}}$$

Where: C = Concentration (dis/min-m^3)

A_o = Activity on filter media at end of sampling period (dis/min)

f = Sampling rate (m^3/min = m^3/h x 1 h/60 minutes)

t_s = Length of sampling time (minute)

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

$t_{\frac{1}{2}}$ = Half-life of isotope or controlling parent (minute)

III. ACTINON CORRECTION

Since the actinon (^{219}Rn) progeny (AcA, AcB & AcC) decays at the AcB half-life of 36 minutes it cannot be distinguished from the radon (^{222}Rn) progeny using standard air sampling with HV-70 or LB5211 filter media and standard alpha counting techniques. A positive displacement pump is used to collect a sample on millipore (0.5 to 0.8 micron) filter media. The sample rate is approximately 20 liters/minute for a sampling time of at least 90 minutes. The center portion of the sample is removed and counted in an alpha spectrometer which exhibits the 6.62 MeV AcC alpha emissions and the 7.69 MeV RaC' alpha emissions. If these two peaks are observed in the spectrum, then the following calculations are performed:

APPENDIX 3
(cont'd.)

$$B_j = \sum_{i=1}^{n} b_{ij}$$

Where: B_j = summation of n channels under peak j.

b_{ij} = the number of counts in channel i of peak j

j = 1 for the 6.62 MeV peak of actinon; 2 for the 7.69 MeV peak of radon.

n = total number of channels in the summation.

The fraction of the activity with a 36-minute half-life due to actinon and radon are then:

$$\text{Actinon} = \frac{B_1/0.84}{B_1/0.84+B_2}$$

$$\text{Radon} = \frac{B_2}{B_1/0.84+B_2}$$

where 1 refers to actinon progeny and 2 refers to radon progeny.

IV. EXAMPLE CALCULATION

Data have been created to correspond to values likely to occur if all possible types of contamination are present in the air of a room where a sample is collected. The application of the equations for determining all types of activity and their concentrations are given below.

Data $f = 40\ m^3/60$ min $\quad t_s = 40$ min
at $t = 100$ min $\quad A = 2000$ dis/min
at $t = 360$ min $\quad A = 140$ dis/min
at $t = 7$ days $\quad A = 5$ dis/min

For long-lived activity:

$$A_o = A = 5 \text{ dis/min}$$

$$C(L) = A_o/fxt_s = \frac{5}{40/60x40} = 0.19 \text{ dis/min-m}^3$$

APPENDIX 3
(cont'd.)

For thoron:

$$A_o = \frac{140-5}{\exp - \frac{0.693 \times 360}{638.4}} = 199.6 \text{ dis/min}$$

$$C(Tn) = \frac{199.6 \times \frac{0.693}{638.4}}{40/60} \times \frac{1}{1 - \exp - \frac{0.693 \times 40}{638.4}} = 7.6 \text{ dis/min-m}^3$$

For radon (^{222}Rn) and actinon (^{219}Rn), activity due to thoron at t = 100 min:

$$A = \frac{135}{\exp - \frac{0.693 \times 260}{638.4}} = 179 \text{ dis/min}$$

Activity due to the isotopes with a 36 minute half-life:

$$A = 2000 - 179 - 5 = 1816 \text{ dis/min}$$

$$A_o = \frac{1816}{\exp - \frac{0.693 \times 100}{36}} = 12{,}454 \text{ dis/min}$$

$$C(36) = \frac{12{,}454 \times \frac{0.693}{36}}{40/60} \times \frac{1}{1 - \exp \frac{-0.693 \times 40}{36}} = 669.7 \text{ dis/min-m}^3$$

When an actinon peak is seen at 6.62 MeV, then the counts under the two peaks are summed. For example, if 10 channels are summed, the following counts are found:

For 6.62 MeV peak:	44 in 10 channels, where the 6.62 alpha emissions are 84% of the total.
For 7.69 MeV peak:	601 counts in 10 channels, where the 7.69 MeV alpha emissions are 100% of the total.

APPENDIX 3
(cont'd.)

$B_1 = 44$

$B_1/0.84 = 52$ counts

$B_2 = 601$ counts

Actinon = 52/653 = 0.08

Radon = 601/653 = 0.92

C(Rn) = C(36) x Radon% = 669.7 x 0.92 = 616.1 dis/min-m^3

C = C(36) x Actinon% = 669.7 x 0.08 = 53.6 dis/min-m^3

Since we assume that on the average half of the progeny is not adhered to the airborne particulates, the above concentrations are then multiplied by 2 to determine actual concentrations. We assume that there is no unattached fraction for the long-lived activity.

C actual = C measured x progeny correction factor

C(L) = 0.19 dis/min-m^3

C(Tn) = 7.6 dis/min-m^3 x 2 = 15.2 dis/min-m^3

C(An) = 53.6 dis/min-m^3 x 2 = 107.2 dis/min-m^3

C(Rn) = 616 dis/min-m^3 x 2 = 1232 dis/min-m^3

These would then be the resulting concentrations in dis/min-m^3. To convert to pCi/ℓ, divide the concentrations by 2.2×10^3.

$$C(L) = \frac{0.19 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3\text{/pCi/}\ell} = 8.6 \times 10^5 \text{ pCi/}\ell$$

$$C(Tn) = \frac{15.2 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3\text{/pCi/}\ell} = 0.0068 \text{ pCi/}\ell$$

$$C(An) = \frac{107.2 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3\text{/pCi/}\ell} = 0.048 \text{ pCi/}\ell$$

$$C(Rn) = \frac{1232 \text{ dis/min-m}^3}{2{,}220 \text{ dis/min-m}^3\text{/pCi/}\ell} = 0.55 \text{ pCi/}\ell$$

APPENDIX 4

SAMPLE PREPARATION AND ANALYSIS GENERIC PROTOCOL

I. SOIL-SAMPLE PREPARATION

Soil samples are acquired as previously described. These samples are bagged and identified at the collection site and returned to ANL. If there is an indication of radioactive contamination, the sample is sealed in a Nalgene jar. At ANL, the soil samples are logged into the soil sample book and weighed. Each soil sample is weighed (on a tared balance scale) and the weight is marked on the container. This weight is recorded in the soil book as a "net weight."

After all samples are marked, weighed, and recorded, they are dried. Each sample is placed in a pyrex beaker marked with the sample identification number. If more than one beaker is necessary, additional numbers (e.g., 1-3, 2-3, 3-3) are used. The original containers are saved for repackaging the dried samples. The beaker is set in an 80°C oven until the soil is dry (approximatley 48 hours). Visual inspection of the soil is sufficient to determine when the soil is dry. The sample is returned to the original container and reweighed using a tared balance scale. This weight is also marked on the container and in the soil sample book where it is referred to as a "dry weight."

After all the samples are returned to their original containers, the milling process is started. Each dried sample is transferred to a 2.3-gallon ceramic mill jar containing mill balls (1¼" x 1¼" Burundum cylinders). The mill jar number is marked on the original container. The jars are sealed and the samples are milled for two hours or until sufficient material is produced to obtain 100 g and 5 g samples for analyses. The samples are milled six at a time. A second set of six jars is prepared while the milling of the first set is proceeding. After each sample is milled, the mill balls are removed with tongs and placed in a tray. A large plastic bag is inverted over the mill jar. Both are inverted and shaken until all the soil is transferred to the bag. If the soil plates the inside of the mill jar, a small paint brush is used to loosen the soil before the jar is inverted. A separate brush is used for each jar to prevent cross-contamination of the soil samples.

After milling, each sample is sieved through a number 30 standard testing sieve (600 μ mesh) and transferred to a 12" x 12" ziplock bag. Rocks and dross are bagged separately. The bags are marked with the sample number, the sieve number and R(rocks) or S(soil). The balance is tared and the weights of the soil (or rocks) are measured and recorded in the soil sample book. A 100-g sample of the sieved material is transferred to a 4-oz. Nalgene bottle. These samples are analyzed by suitable analytical techniques, including, as a minimum, gamma spectroscopy (GeLi) and radiochemical analyses for plutonium, americium and thorium. A 5-g sample of the sieved material is transferred to a 1-oz Nalgene bottle.

APPENDIX 4
(cont'd.)

This sample is used for the determination of uranium by laser fluorometry. The bottles containing these weighed samples are marked with sample number and date and this information is recorded in the soil sample book. The rocks (and dross) and remaining soil are placed in storage.

The sieves, mill jars, and Burundum milling balls used in this work are classified in two sets. One set is used for background samples exclusively. The other set is used for all samples from suspect areas. Soil samples with elevated levels of radioactivity based on instrument measurements are milled in one-gallon Nalgene bottles using Burundum balls from the set used for suspect samples. After use, these balls are either decontaminated (see below) or disposed of as radioactive waste. The Nalgene bottles are always disposed of as radioactive waste. The sieves used for these samples are also from the set used for suspect samples and are decontaminated after use.

II. EQUIPMENT DECONTAMINATION

The care of the milling apparatus is as important as the actual sample preparation. Proper care prevents cross-contamination of successive samples. The beakers used to dry the samples are washed thoroughly by placing a small amount of Haemo-Sol in each beaker and filling with warm water. The beaker is then scrubbed thoroughly on the inside and scoured on the outside with scouring powder. The beakers are then rinsed with tap water (three times) followed by demineralized water (three times) and finally dried thoroughly before reuse.

The milling apparatus (tongs, brushes, milling jars, lids and milling balls) are rinsed. The tongs and brushes are washed thoroughly with Haemo-Sol. Eight Burundum balls are returned to each milling jar along with about one pint of ~~clean~~ road gravel, one spoon of Haemo-Sol, one spoon of scouring powder with bleach, and one quart of water. The lid is tightened on the jar and the jar is placed on the rolling mill and rolled for approximately two hours or until the balls and the inside of the jar appear to be physically clean. After this time, the mill jar is removed from the rolling mill and its contents are dumped into a screen or basket. The lid and balls are then rinsed thoroughly three times with tap water followed by three times with demineralized water. The inside of the jar is rinsed until it is absolutely clean. The milling apparatus is air dried using warm air until absolutely dry. Air is blown through a hose from the oven to the inside of the ceramic jar to dry the jar.

The sieves are rinsed, washed in Haemo-Sol, thoroughly rinsed (three times with tap water, followed by three rinses with demineralized water) and then air dried as above before reuse.

III. WATER AND SLUDGE

Water samples are collected in 0.1-liter, 0.5-liter and/or 1-liter quantities as deemed appropriate. These samples are forwarded directly to a certified radiochemistry laboratory for preparation and analysis. The customary analysis procedure consists of filtration to obtain the suspended solids followed by

APPENDIX 4
(cont'd.)

evaporation to obtain the dissolved solids. Both suspended and dissolved solids are analyzed by appropriate radiochemical analytical techniques.

Sludge samples are collected in 0.1-liter bottles and are processed as outlined above for water samples.

IV. VEGETATION, TRASH AND RUBBLE

Samples of potentially contaminated vegetation, trash (e.g. piping, ducts, conduit, etc.) and rubble are collected, bagged, and labeled at the site and returned to ANL for analysis.

Vegetation samples are initially weighed and transferred to Marinelli beakers for gamma spectrometric analysis. Then they are ashed, reweighed, and analyzed by appropriate analytical techniques.

Trash and rubble samples are forwarded to a certified radiochemistry laboratory for analysis.

V. TRITIUM FROM SOLID MATERIALS

Samples of solid materials (e.g., concrete) suspected of containing tritium are collected, broken into small pieces and submitted to a certified radiochemistry laboratory for analysis. The standard analytical procedure consists of transferring a 20-40 g sample to a ceramic boat followed by heating in a tube furnace at 425°C for a period of two hours (~ 40 min to reach temperature and ~ 80 min heating at temperature). Helium is used as a flow gas through the tube during heating, and the tritium is collected in two traps on the downstream side of the furance. The first trap is immersed in an ordinary ice bath (0°C); the second trap is immersed in a CO_2-Freon bath (-57°C). The collected tritiated water from both traps is combined, made up to a known volume, and an aliquot taken for liquid scintillation counting of the tritium.

VI. ANALYSIS PROCEDURES

A 100-g fraction from each soil sample is analyzed by high resolution gamma-ray spectroscopy using a germanium crystal detector coupled to a multichannel analyzer. This analysis allows for a quantitative determination of the ^{226}Ra decay chain (via the 609 keV γ-ray of ^{214}Bi) and the ^{232}Th decay chain (via the 908 keV γ-ray of ^{228}Ac as well as any other gamma emitting radionuclide (e.g. ^{137}Cs) present in the soil.

The total uranium (elemental) present in the soil is determined by an acid leach of the soil sample followed by laser fluorometry of the leached sample.

Thorium analysis consists of an acid leach of the soil (using a ^{234}Th spike for yield determination) followed by plating a thin source of the radiochemically separated thorium and determining the thorium isotopes (^{228}Th and ^{232}Th) by alpha spectroscopy.

APPENDIX 4
(cont'd.)

The results of the above measurements allow for quantitative determination of the relative amounts of normal uranium, natural uranium, tailings (i.e., ^{226}Ra decay chain), thorium (^{232}Th), mesothorium (^{228}Ra decay chain) and thorium (^{228}Th) decay chain present in the contaminated material.

A mass spectrometric analysis of the uranium fraction is conducted when it is known or is is surmised that depleted or enriched uranium might be present.

APPENDIX 5

CALCULATION OF NORMAL-URANIUM SPECIFIC ACTIVITY

The specific activity for normal uranium was obtained by summing the measured specific activities for the individual isotopes weighted according to their normal abundances. Best values for these specific activities were taken from A. H. Jaffey, et al. Phys. Rev. 4 1889 (1971). The percent abundance and half-life for each isotope were taken from the "Table of Isotopes," 7th Edition by C. M. Lederer and V. S. Shirley (1978). Atomic weights were taken from the Handbook of Chemistry and Physics, 52nd Edition (1971).

Isotope	Specific Activity	Half-life (years)	Abundance (atom %)	Atomic Weight (grams)	Abundance (wt %)
^{234}U	-	2.446×10^5	0.0054	234.0409	0.0053
^{235}U	4.798 dis/min-g	7.038×10^8	0.7196	235.0439	0.7106
^{238}U	0.746 dis/min-μg	4.4683×10^9	99.2747	238.0508	99.2841
			99.9997		100.0000

where $(\text{wt }\%)_i =$

$$\frac{(\text{atom }\%)_i \ (\text{atomic weight})_i}{\sum_{\text{all } j}(\text{atom }\%)_j \ (\text{atomic weight})_j} = \frac{(\text{atom }\%)_i \ (\text{atomic weight})_i}{238.02985}$$

Specific activity for normal uranium:

$$\begin{aligned} 0.746 \times 0.99284 \times 2 &= 1.481 && \text{dis/min-}\mu\text{g from } 234 \ \& \ ^{238}U \\ 4.798 \times 0.00711 &= \underline{0.0341} && \text{dis/min-}\mu\text{g from } ^{235}U \\ & 1.515 && \text{dis/min-}\mu\text{g for normal U} \end{aligned}$$

or $(1.515 \text{ dis/min-}\mu\text{g})/(2.22 \text{ dis/min-pCi}) = 0.683 \text{ pCi}/\mu\text{g}$

where ^{234}U is assumed to be in secular equilibrium with the ^{238}U parent.

Note that 2.25% of the total activity is due to ^{235}U and 48.87% each is due to ^{234}U and ^{238}U.

APPENDIX 6

PERTINENT RADIOLOGICAL REGULATIONS, STANDARDS, AND GUIDELINES

Excerpts From

I. DRAFT AMERICAN NATIONAL STANDARD

N13.12

Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use

Where potentially contaminated surfaces are not accessible for measurement (as in some pipes, drains, and ductwork), such property shall not be released pursuant to this standard, but shall be made the subject of case-by-case evaluation.

Property shall not be released for uncontrolled use unless measurements show the total and removable contamination levels to be no greater than the values in Table 1 or Table 2. (The values in Table 2 are easier to apply when the contaminants cannot be individually identified.)

Coatings used to cover the contamination shall not be considered a solution to the contamination problem. That is, the monitoring techniques shall be sufficient to determine, and such determination shall be made, that the total amount of contamination present on and under any coating does not exceed the Table 1 or Table 2 values before release.

APPENDIX 6
(Cont'd.)

TABLE 1

SURFACE CONTAMINATION LIMITS*

Contaminants			Limit (Activity)+ (dis/min-100 cm^2)	
Group	Description	Nuclides (Note 1)	Removable	Total (Fixed plus Removable)
1	Nuclides for which the nonoccupational MPC$_a$ (Note 2) is 2×10^{-13} Ci/m^3 or less or for which the nonoccupational MPC$_w$ (Note 4) is 2×10^{-7} Ci/m^3 or less	^{227}Ac ^{241,242m,243}Am ^{249,250,251,252}Cf ^{243,244,245,246,247,248}Cm ^{125,129}I ^{237}Np ^{231}Pa ^{210}Pb ^{238,239,240,242,244}Pu ^{226,228}Ra ^{228,230}Th	20	Nondetectable (Note 3)
2	Those nuclides not in Group 1 for which the nonoccupational MPC$_a$ (Note 2) is 1×10^{-12} Ci/m^3 or less for which the nonoccupational MPC$_w$ (Note 4) is 1×10^{-6} Ci/m^3 or less	^{254}Es ^{256}Fm ^{126,131,133}I ^{210}Po ^{223}Ra ^{90}Sr ^{232}Th ^{232}U	200	2000 α Nondetectable β,γ (Note 5)
3	Those nuclides not in Group 1 or Group 2		1000	5000

APPENDIX 6
(Cont'd.)

SURFACE CONTAMINATION LIMITS

*The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm^2 is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm^2, if (1) from measurements of a representative number n of sections it is determined that $1/n \sum_n S_i \geq L$, where S_i is the dis/min-100 cm^2 determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm^2 exceeds 3 L.

+Disintegrations per minute per square decimeter.

NOTES:

(1) Values presented here are obtained from the Code of Federal Regulations, Title 10, Part 20, April 30, 1975. The most limiting of all given MPC values (for example, soluble versus insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fraction shall be less than 1.

(2) Maximum permissible concentration in air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as the National Committee on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), or the Nuclear Regulatory Commission (NRC). From the Code of Federal Regulations, Title 10, Part 20, Appendix B, Table 2, Column 1.

(3) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm^2.

(4) Maximum permissible concentration in water applicable to members of the public.

(5) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey for unconditional release should be performed in areas where the background is $\leqq$ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

APPENDIX 6
(Cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

(All Alpha Emitters, except U_{nat} and Th_{nat}, Considered as a Group)*

	Limit (Activity) (dis/min-100 cm^2)$^+$	
Contamination Contingencies	Removable	Total (Fixed Plus Removable
If the contaminant cannot be identified; or if alpha emitters other than U_{nat} (Note 1) and Th_{nat} are present; or if the beta emitters comprise ^{227}Ac or ^{228}Ra.	20	Nondetectable (Note 2)
If it is known that all alpha emitters are generated from U_{nat} (Note 1) and Th_{nat}; and if beta emitters are present that, while not identified, do not include ^{227}Ac, ^{125}I, ^{226}Ra, and ^{228}Ra.	200	2000 α Nondetectable β,γ (Note 3)
If it is known that alpha emitters are generated only from U_{nat} (Note 1) and Th_{nat} in equilibrium with its decay products; and if the beta emitters, while not identified, do not include ^{227}Ac, ^{125}I, ^{129}I, ^{90}Sr, ^{223}Ra, ^{228}Ra, ^{126}I, ^{131}I and ^{133}I.	1000	5000

APPENDIX 6
(Cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

[*] The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm^2 is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm^2, if (1) from measurements of a representative number n of sections it is determined that $1/n \sum_n S_i \geq L$, where S_i is the dis/min-100 cm^2 determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm^2 exceeds 3 L.

[+] Disintegrations per minute per square decimeter.

NOTES:

(1) U_{nat} and decay products.

(2) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm^2.

(3) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey of unconditional release should be performed in areas where the background is $\leqq$ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

II. GUIDELINES FOR DECONTAMINATION OF FACILITIES AND EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED USE OR TERMINATION OF LICENSES FOR BY-PRODUCT SOURCE, OR SPECIAL NUCLEAR MATERIAL

(These have been retyped for
purposes of this report)

The instructions in this guide, in conjunction with Table 1, specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table 1 do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.

2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table 1 prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.

3. The radioactivity on the interior surfaces of pipes, drain lines, or duct work shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or duct work. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.

4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer of premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:

    a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.

APPENDIX 6
(Cont'd.)

b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table 1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

   a. Identify the premises.

   b. Show that reasonable effort has been made to eliminate residual contamination.

   c. Describe the scope of the survey and general procedures followed.

   d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

APPENDIX 6
(Cont'd.)

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LIMITS

NUCLIDES[a]	AVERAGE[bcf]	MAXIMUM[bdf]	REMOVABLE[bef]
U-nat, ^{235}U, ^{238}U and associated decay products	5000 dis/min-100 cm^2 α	15,000 dis/min-100 cm^2 α	1000 dis/min-100 cm^2 α
Transuranics, ^{226}Ra, ^{228}Ra, ^{230}Th, ^{228}Th, ^{231}Pa, ^{227}Ac, ^{125}I, ^{129}I	100 dis/min-100 cm^2	300 dis/min-100 cm^2	20 dis/min-100 cm^2
Th-nat, ^{232}Th ^{90}Sr, ^{223}Ra, ^{224}Ra, ^{232}U, ^{126}I, ^{131}I, ^{133}I	1000 dis/min-100 cm^2	3,000 dis/min-100 cm^2	200 dis/min-100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr and others noted above.	5000 dis/min-100 cm^2 $\beta\gamma$	15,000 dis/min-100 cm^2 $\beta\gamma$	1000 dis/min-100 cm^2 $\beta\gamma$

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(Cont'd.)

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LEVELS

[a] Where surface contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for alpha and beta-gamma emitting nuclides should apply independently.

[b] As used in this table, dis/min (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c] Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d] The maximum contamination level applies to an area of not more than 100 cm^2.

[e] The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

[f] The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

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III. SURGEON GENERAL'S GUIDELINES
as included in 10 CFR Part 712
Grand Junction Remedial Action Criteria

712.1 Purpose

(a) determination by DOE of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colorado, to radiation emanating from uranium mill tailings which have been used as construction-related material.

(b) The regulations in this part are issued pursuant to Pub. L. 92-314 (86 Stat. 222) of June 16, 1972.

712.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colorado, under or adjacent to which uranium mill tailings have been used as a construction-related material between January 1, 1951, and June 16, 1972, inclusive.

712.3 Definitions

As used in this part:

(a) "Administrator" means the Administrator of Energy Research and Development or his duly authorized representative.

(b) "Area of Grand Junction, Colorado," means Mesa County, Colorado.

(c) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.

(d) "DOE" means the U.S. Department of Energy or any duly authorized representative thereof.

(e) "Construction-related material" means any material used in the construction of a structure.

(f) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

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(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) averaging the results of six air samples each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen" (mR) means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-214), Radium C (bismuth-214), and Radium C' (polonium-214).

(k) "Remedial action" means any action taken with a reasonable expectation of reducing the radiation exposure resulting from uranium mill tailings which have been used as construction-related material in and around structures in the area of Grand Junction, Colorado.

(l) "Surgeon General's Guidelines" means radiation guidelines related to uranium mill tailings prepared and released by the Office of the U.S. Surgeon General, Department of Health, Education and Welfare on July 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium milling operation involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

712.4 Interpretations

Except as specifically authorized by the Administrator in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of DOE other than a written interpretation by the General Counsel will be recognized to be binding upon DOE.

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Department of Energy, Washington, D.C. 20545.

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712.6 General radiation exposure level criteria for remedial action.

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommended the following graded action levels for remedial action in terms of external gamma radiation level (EGR) and indoor radon daughter concentration level (RDC) above background found within dwellings constructed on or with uranium mill tailings.

EGR	RDC	Recommendation
Greater than 0.1 mR/h	Greater than 0.05 WL	Remedial action indicated.
From 0.05 to 0.1 mR/h	From 0.01 to 0.05 WL	Remedial action may be suggested.
Less than 0.05 mR/h	Less than 0.01 WL	No remedial action indicated

712.7 Criteria for determination of possible need for remedial action

Once it is determined that a possible need for remedial action exists, the record owner of a structure shall be notified of that structure's eligibility for an engineering assessment to confirm the need for remedial action and to ascertain the most appropriate remedial measure, if any. A determination of possible need will be made if as a result of the presence of uranium mill tailings under or adjacent to the structure, one of the following criteria is met:

(a) Where DOE approved data on indoor radon daughter concentration levels are available

(1) For dwellings and schoolrooms: An indoor radon daughter concentration level of 0.01 WL or greater above background.

(2) For other structures: An indoor radon daughter concentration level of 0.03 WL or greater above background.

(b) Where DOE approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/h or greater above background.

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(Cont'd.)

(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(A) It may be presumed that if the external gamma radiation level is equal to or exceed 0.02 mR/h above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

(B) It should be presumed that if the external gamma radiation level is less than 0.001 mR/h above background, the indoor radon daughter concentration level is less than 0.01 WL above background, and no possible need for remedial actions exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/h above background but is less than 0.02 mR/h above background, measurements will be required to ascertain the indoor radon daughter concentration level.

(2) For other structures:

(i) An external gamma radiation level of 0.15 mR/h above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiation level/indoor radon daughter concentration level relationship. Decisions will be made in individual cases based upon the results of actual measurements.

712.8 Determination of possible need for remedial action where criteria have not been met.

The possible need for remedial action may be determined where the criteria in 712.7 have not been met if various other factors are present. Such factors include, but are not necessarily limited to, size of the affected area, distribution of radiation levels in the affected area, amount of tailings, age of individuals occupying affected area, occupancy time, and use of the affected area.

712.9 Factors to be considered in determination of order of priority for remedial action.

In determining the order or priority for execution of remedial action, consideration shall be given, but not necessarily limited to, the following factors:

(a) Classification of structure. Dwellings and schools shall be considered first.

(b) Availability of data. Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in 712.7 will be considered first.

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(g) Climatic conditions. Climatic conditions or other seasonable considerations may affect the scheduling of certain remedial measures.

712.10 Selection of appropriate remedial action.

(a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/h above background in the case of dwellings and schools and 0.15 mR/h above background in the case of other structures.

(b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. DOE shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

IV. EXCERPTS FROM DOE 5480.1, Chapter XI

"Requirements for Radiation Protection"

Exposure of Individuals and Population Groups in Uncontrolled Areas. Exposures to members of the public shall be as low as reasonably achievable levels within the standards prescribed below.

Radiation Protection Standards
for Internal and External Exposure
of Members of the Public

	Annual Dose Equivalent or Dose Commitment	
Type of Exposure	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on Average Dose to a Suitable Sample of the Exposed Population
Whole body, gonads, or bone marrow	0.5 rem (or 500 mrem)	0.17 rem (or 170 mrem)
Other organs	1.5 rem (or 1500 mrem)	0.5 rem (or 500 mrem)

APPENDIX 7

ESTIMATED EXTENT OF CONTAMINATION

Estimates of the extent of the contamination at the assessed site are based on the total volume, mass, and quantity of radioactive material in the contaminated area. The volume is the product of the surface area and the depth of the contamination. The mass is the product of the volume and the density of the material. A density of 1.5 g/cm^3 is used for soil. The concentration (pCi/g) of the specific radioisotope is determined by radiochemical analysis of the soil. The total quantity of radioactive material is the product of the concentration of the specific radioisotope and the total mass of material.

Often there is more than one contaminant in the soil (or contaminated material) and the contaminants are not uniformly distributed throughout the material. In these cases, it is necessary to estimate the fraction of the material containing each contaminant in order to assess the total quantity of the radioactive material. This estimate of the fraction of the material containing each contaminant is based on the radiochemical analysis of randomly selected samples.

Estimates of the extent of contamination are usually determined for averaged (Option 1) and maximum or worst-case (Option 2) conditions. Sample calculations for the extent of contamination in the Back Forty area of the Albany, Oregon Bureau of Mines Site are as follows:

Volume (Average) = 34,800 ft^2 (area) x 3.6 ft (avg. depth) = 125,000 ft^3
= 3,550 m^3

Volume (Maximum) = 34,800 ft^2 (area) x 9 ft (max. depth) = 314,000 ft^3
= 8,880 m^3

Mass (Average) = 3,550 m^3 x 1,500 kg/m^3 = 5.33 x 10^6 kg
Mass (Maximum) = 8,880 m^3 x 1,500 kg/m^3 = 1.33 x 10^7 kg

Estimated Total Activity for ^{226}Ra (chain)

Average: 5.33 x 10^6 kg x 14 x 10^{-12} Ci/g x 10^3 g/kg x .05 (fraction)* = 0.004 Ci

Maximum: 1.33 x 10^7 kg x 16 x 10^{-12} Ci/g x 10^3 g/kg x .05 (fraction)* = 0.011 Ci

*This represents the estimate of the fraction of the total mass contaminated with the ^{226}Ra chain.

APPENDIX 8

EVALUATION OF RADIATION EXPOSURES

INTRODUCTION

A. Types of Radiation

Radiation is the emission or transmission of energy in the form of waves or particles. Examples are acoustic waves (i.e., sound), electromagnetic waves (such as radio, light, x- and gamma-rays), and particulate radiations (such as alpha particles, beta particles, neutrons, protons, and other elementary particles).

The class of radiation of importance to this report is known as ionizing radiation. Ionizing radiations are those, either electromagnetic or particulate, with sufficient energy to ionize matter, i.e., to remove or displace electrons from atoms and molecules. The most common types of ionizing radiation are x- and gamma-rays, alpha particles, beta particles, and neutrons.

X- and gamma-rays are electromagnetic waves of pure energy, having no charge and no mass or existence at rest. Gamma-rays and x-rays are identical except that x-rays originate in the atom and gamma-rays originate in the nucleus of an atom. X- and gamma-rays are highly penetrating and can pass through relatively thick materials before interacting. Upon interaction, some or all of the energy is transferred to electrons which, in turn, produce additional ionizations while coming to rest.

Alpha particles are positively charged particulates composed of two neutrons and two protons, identical to the nucleus of a helium atom. Due to its comparatively large mass and double charge, an alpha particle interacts readily with matter and penetrates only a very short distance before coming to rest, causing intense ionization along its path.

Beta particles are negatively charged free electrons moving at high speeds. Due to its comparatively small mass and single charge, a beta particle's penetration through matter is intermediate between that of the alpha particle and the gamma-ray, causing fewer ionizations per unit path length than an alpha particle.

B. Sources of Radiation

Ionizing radiations arise from terrestrial radioactive materials (both naturally occurring and man-made), extra-terrestrial (cosmic) sources, and radiation-producing machines. The sources of ionizing radiation important to this report are radioactive materials and cosmic sources.

Most atoms of the elements in our environment remain structurally stable. With time, an atom of potassium, for instance, may change its association with other atoms in chemical reactions and become part of other compounds, but it will always remain a potassium atom. Radioactive atoms, on the other hand, are

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not stable and will spontaneously emit radiation in order to achieve a more stable state. Because of this spontaneous transformation, the ratio of protons and neutrons in the nucleus of an atom is altered toward a more stable condition. Radiation may be emitted from the nucleus as alpha particles, beta particles, neutrons, or gamma-rays, depending uniquely upon each particular radionuclide. Radionuclides decay at characteristic rates dependent upon the degree of stability and characterized by a period of time called the half-life. In one half-life, the number of radioactive atoms and, therefore, the amount of radiation emitted, decrease by one half.

The exposure of man to terrestrial radiation is due to naturally occurring radionuclides and also to "man-made" or technologically enhanced radioactive materials. Several dozen radionuclides occur naturally, some having half-lives of at least the same order of magnitude as the estimated age of the earth. The majority of these naturally occurring radionuclides are isotopes of the heavy elements and belong to three distinct radioactive series headed by uranium-238, uranium-235, and thorium-232. Each of these decays to stable isotopes of lead (Pb) through a sequence of radionuclides of widely varying half-lives. Other naturally occurring radionuclides, which decay directly to a stable nuclide, are potassium-40 and rubidium-87. It should be noted that even though the isotopic abundance of potassium-40 is less than 0.012%, potassium is so widespread that potassium-40 contributes about one-third of the radiation dose received by man from natural background radiation. A major portion of the exposure (dose) of man from external terrestrial radiation is due to the radionuclides in the soil, primarily potassium-40 and the radioactive decay-chain products of thorium-232 and uranium-238. The naturally occurring radionuclides deposited internally in man through uptake by inhalation/ingestion of air, food, and drinking water containing the natural radioactive material also contribute significantly to his total dose. Many other radionuclides are referred to as "man made" in the sense that they can be produced in large quantities by such means as nuclear reactors, accelerators, or nuclear weapons tests.

The term "cosmic radiation" refers both to the primary energetic particles of extra-terrestrial origin that are incident on the earth's atmosphere and to the secondary particles that are generated by the interaction of these primary particles with the atmosphere, and reach ground level. Primary cosmic radiation consists of "galactic" particles externally incident on the solar system, and "solar" particles emitted by the sun. This radiation is composed primarily of energetic protons and alpha particles. The first generation of secondary particles (secondary cosmic radiation), produced by nuclear interactions of the primary particles with the atmosphere, consists predominantly of neutrons, protons, and pions. Pion decay, in turn, results in the production of electrons, photons, and muons. At the lower elevations, the highly penetrating muons and their associated decay and collision electrons are the dominant components of the cosmic-ray particle flux density. These particles, together with photons from the gamma-emitting, naturally occurring radionuclides in the local environment, form the external penetrating component of the background environmental radiation field which provides a significant portion of the whole-body radiation dose to man.

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In addition to the direct cosmic radiation, cosmic sources include cosmic-ray-produced radioactivity, i.e., cosmogenic radionuclides. The major production of cosmogenic radionuclides is through interaction of the cosmic rays with the atmospheric gases through a variety of spallation or neutron-capture reactions. The four cosmogenic radionuclides that contribute a measurable radiation dose to man are carbon-14, sodium-22, beryllium-7, and tritium (hydrogen-3), all produced in the atmosphere.

BACKGROUND RADIATION DOSES

Background radiation doses are comprised of an external component of radiation impinging on man from outside the body and an internal component due to radioactive materials taken into the body by inhalation or ingestion.

Radiation dose may be expressed in units of rads or rems, depending upon whether the reference is to the energy deposited or to the biological effect. A rad is the amount of radiation that deposits a certain amount of energy in each gram of material. It applies to all radiations and to all materials which absorb that radiation.

Since different types of radiation produce ionizations at different rates as they pass through tissue, differences in damage to tissues (and hence the biological effectiveness of different radiations) has been noticed. A rem is defined as the amount of energy absorbed (in rads) from a given type of radiation multiplied by the factor appropriate for the particular type of radiation in order to approximate the biological damage that it causes relative to a rad of x or gamma radiation. The concept behind the unit "rem" permits evaluation of potential effects from radiation exposure without regard to the type of radiation or its source. One rem received from cosmic radiation results in the same biological effects as one rem from medical x-rays or one rem from the radiations emitted by naturally occurring or man-made radioactive materials.

The external penetrating radiation dose to man derives from both terrestrial radioactivity and cosmic radiation. The terrestrial component is due primarily to the gamma dose from potassium-40 and the radioactive decay products of thorium-232 and uranium-238 in soil as well as from the beta-gamma dose from radon daughters in the atmosphere. Radon is a gaseous member of the uranium-238 chain. The population-weighted external dose to an individual's whole body from terrestrial sources in the United States has been estimated as 15 mrem per year for the Atlantic and Gulf Coastal Plain, 57 mrem per year for an indeterminate area along the Rocky Mountains, and 29 mrem per year for the majority of the rest of the United States. The overall population-weighted external dose for the U.S. population as a whole has been estimated to be 26 mrem per year.

The cosmic radiation dose, due to the charged particles and neutrons from secondary cosmic rays, is typically about 30% to 50% of the total from all external environmental radiation. The cosmic-ray dose to the population is estimated to be 26 mrem per year for those living at sea level, and increases with increasing altitude. Considering the altitude distribution of the U.S.

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population, the population-weighted external cosmic-ray dose is 28 mrem per year. The population-weighted total external dose from terrestrial plus cosmic sources is thus 54 mrem per year for the U.S. population as a whole.

The internal radiation doses derive from terrestrial and cosmogenic radionuclides deposited within the body through uptake by inhalation/ingestion of air, food, and drinking water. Once deposited in the body, many radioactive materials can be incorporated into tissues because the chemical properties of the radioisotopes are identical or similar to stable isotopes in the tissues. Potassium-40, for instance, is incorporated into tissues in the same manner as stable potassium atoms because the chemical properties are identical; radioactive radium and strontium can be incorporated into tissues in the same manner as calcium because their chemical properties are similar. Once deposited in tissue, these radionuclides emit radiation that results in the internal dose to individual organs and/or the whole body as long as it is in the body.

The internal dose to the lung is due primarily to the inhalation of polonium-218 and -214 (radon daughters), lead-212 and bismuth-212 (thoron daughters) and polonium-210 (one of the longer-lived radon decay products). The dose to the lung is about 100 mrem per year from inhaled natural radioactivity. The internal dose from subsequent incorporation of inhaled or ingested radioactivity is due to a beta-gamma dose from incorporation of potassium-40, rubidium-87, and cosmogenic nuclides, and an alpha dose from incorporation of primarily polonium-210, radium-226 and -228, and uranium-238 and -234. The dose to man from internally incorporated radionuclides is about 28 mrem per year to the gonads, about 25 mrem per year to the bone marrow, lung, and other soft tissues, and about 117 mrem per year to the bone (osteocytes). The bone dose arises primarily from the alpha-emitting members of the naturally occurring series, with polonium-210 being the largest contributor. The gonadal and soft tissue doses arise primarily from the beta and gamma emissions from potassium-40. The total internal dose from inhaled plus incorporated radioactivity is about 28 mrem per year to the gonads (or whole-body dose), about 125 mrem per year to the lung, about 25 mrem per year to the bone marrow, and about 117 mrem per year to the bone (osteocytes).

The total natural background radiation dose is the sum of the external and internal components. The population-weighted dose for the U.S. population as a whole is about 82 mrem per year to the gonads or whole body, about 179 mrem per year to the lung, about 79 mrem per year to the bone marrow, and about 171 mrem per year to the bone (osteocytes).

Besides the natural background radiation, background radiation doses include contributions from man-made or technologically enhanced sources of radiation. By far, the most significant are x-ray and radiopharmaceutical medical examinations. These contribute a population-averaged dose estimated to be 70 mrem per year for the U.S. population as a whole. Fallout from nuclear weapons testing through 1970 has contributed 50-year dose commitments estimated as 80 mrem external, and 30, 20, and 45 mrem internal to the gonads, lung, and bone marrow, respectively. Contributions from the use of fossil fuels (natural gas and coal) and nuclear reactors; mining, milling, and tailings piles; television sets, smoke detectors, and watch dials could be responsible for an additional 5 mrem per year, averaged over the U.S. population as a whole. In addition, the use of radiation or radioactivity for scientific, industrial, or medical purposes may cause workers in the industry and, to a lesser extent, members of the general public, to receive some radiation exposure above natural background.

EVALUATION OF RADIATION DOSE AND POTENTIAL HAZARD

Radiation, regardless of its sources, is considered to be a hazard because of its potential for producing adverse effects on human life. Very large amounts of radiation received over a brief period, i.e., hundreds of rem delivered within a few hours, can produce severe injury or death within days or weeks. Distributed over longer intervals, however, these same doses would not cause early illness or fatality. At doses and rates too low to produce these immediate symptoms, chronic or repeated exposure to radiation can bring about biological damage which does not appear until years or decades later. These low-level effects are stochastic in nature; their probability rather than their severity increases with dose. Primary among these latent or delayed effects are somatic effects, where insults such as cancers occur directly to the individual exposed, and genetic defects, where, through damage to the reproductive cells of the exposed individual, disability and disease ranging from subtle to severe are transmitted to his offspring.

Clinical or observed evidence of a relationship between radiation and human cancers arise from several sources. The most important data come from the victims of Hiroshima and Nagasaki, patients exposed during medical therapy, radium dial painters, and uranium miners. Data exist only for relatively large doses; there have been no direct measurements of increased incidence of cancer for low-level radiation exposures. Evaluation of the available data has lead to estimates of the risk of radiation-induced cancer; estimated risks for the lower doses have been derived by linear extrapolation from the higher doses. All radiation exposures then, no matter how small, are assumed to be capable of increasing an individual's risk of contracting cancer.

Data on genetic defects resulting from radiation exposure of humans is not available to the extent necessary to allow an estimate of the risk of radiation-induced effects. Data from animals, along with general knowledge of genetics, have been used to derive an estimate of the risks of genetic effects.

Estimates of health effects from radiation doses are usually based on risk factors as provided in International Commission on Radiological Protection (ICRP), National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), or United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) reports. Multiplying the estimated dose by the appropriate risk factor provides an estimate of the risk or probability of induction of health effects to an individual or his descendants as a result of that exposure. The evaluation of these risk factors is presently subject to large uncertainties and, therefore, potential continual revision. The risk

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factors recommended by the ICRP for cancer mortality and hereditary ill health to the first and second generations are 10^{-4} per rem of whole-body dose and 4×10^{-5} per rem of gonadal dose, respectively. As an example, a whole-body dose of 1 rem would be estimated to add a risk of cancer mortality to the exposed invididual of 10^{-4}, i.e., 1 chance in 10,000. However, a precise numerical value cannot be assigned with any certainty to a particular individual's increase in risk attributable to radiation exposure. The reasons for this are numerous and include the following: (1) uncertainties over the influence of the individual's age, state of health, personal habits, family medical history, and previous or concurrent exposure to other cancer-causing agents, (2) the variability in the latent period (time between exposure and physical evidence of disease), and (3) the uncertainty in the risk factor itself.

To be meaningful, an attempt should be made to view such risk estimates in the appropriate context. One useful comparison is with risks encountered in normal life. Another comparison, potentially more useful, is with an estimation of the risks attributable to natural background radiation. Radiation from natural external and internal radioactivity results in the same types of interactions with body tissues as that from "man-made" radioactivity. Hence, the risks from a specified dose are the same regardless of the source. Rather than going through an intermediate step involving risk factors, doses can also be compared directly to natural background radiation doses.

Besides estimation of risks and comparisons to natural background, doses may be compared to standards and regulations. The appropriate standards, the Department of Energy's "Requirements for Radiation Protection," give limits for external and internal exposures for the whole body and specified organs which are expressed as the permissible dose or dose commitment annually in addition to natural background and medical exposures. There are, in general, two sets of limits, one applicable to occupationally exposed persons and the second applicable to individuals and population groups of the general public. The limits for individuals of the public are one-tenth of those permitted for occupationally exposed individuals. The set of limits important to this report are those applicable to individuals and population groups of the public. The limits for individuals of the public are 500 mrem per year to the whole body, gonads, or bone marrow and 1500 mrem per year to other organs. The limits for population groups of the public are 170 mrem to the whole body, gonads, or bone marrow and 500 mrem per year to other organs, averaged over the group. In either case, exposures are to be limited to the lowest levels reasonably achievable within the given limits.

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